

✓

**MERCURY  
IN  
MICHIGAN'S ENVIRONMENT:  
ENVIRONMENTAL AND HUMAN HEALTH CONCERNS**

**(A Science Report to Governor John Engler)**

**MICHIGAN ENVIRONMENTAL SCIENCE BOARD  
LEWIS CASS BUILDING  
P.O. Box 36026  
LANSING, MICHIGAN 48909**

**APRIL 1993**

**(THIRD PRINTING)**

STATE OF MICHIGAN



JOHN ENGLER, Governor

DEPARTMENT OF MANAGEMENT & BUDGET

P.O. BOX 30026, LANSING, MICHIGAN 48909

PATRICIA A. WOODWORTH, Director

May 13, 1993

The Honorable John Engler, Governor  
State of Michigan  
Executive Office  
P.O. Box 30013  
Lansing, Michigan 48909

Dear Governor Engler:

We are pleased to submit to you the results of the mercury investigation conducted by the Michigan Environmental Science Board. The report, entitled Mercury in Michigan's Environment: Environmental and Human Health Concerns, constitutes an eight month investigation and specifically addresses the concerns raised by you in your August 6, 1992 correspondence.

The Board appreciates the opportunity afforded it to serve the state and looks forward to its next assignment.

Sincerely,

A handwritten signature in cursive script, appearing to read "Lawrence J. Fischer".

Lawrence J. Fischer, Ph.D., Chair  
Michigan Environmental Science Board

A handwritten signature in cursive script, appearing to read "Keith G. Harrison".

Keith G. Harrison, M.A., R.S., Cert. Ecol.  
Executive Director  
Michigan Environmental Science Board

cc: Dr. Jonathan W. Bulkley, Member  
Dr. Richard J. Cook, Member  
Dr. Raymond Y. Demers, Member  
Dr. David T. Long, Member  
Dr. Ronald H. Olsen, Member  
Dr. Bette J. Premo, Member  
Dr. Eileen O. van Ravenswaay, Member  
Dr. George T. Wolff, Member  
Roland Harmes, Director, DNR  
Vernice Davis Anthony, Director, DPH  
Steve Fetter, Chair, PSC



**MICHIGAN ENVIRONMENTAL SCIENCE BOARD MERCURY PANEL**

Lawrence J. Fischer, Ph.D.....Chairperson  
Jonathan W. Bulkley, Ph.D.....Panel Member  
Richard J. Cook, Ph.D.....Panel Member  
Raymond Y. Demers, M.D.....Panel Member  
David T. Long, Ph.D.....Panel Member  
Ronald H. Olsen, Ph.D.....Panel Member  
Bette J. Premo, Ph.D.....Panel Member  
Eileen O. van Ravenswaay, Ph.D.....Panel Member  
George T. Wolff, Ph.D.....Panel Member

**MICHIGAN ENVIRONMENTAL SCIENCE BOARD**

Lawrence J. Fischer, Ph.D.....Chairperson  
Jonathan W. Bulkley, Ph.D.....Board Member  
Richard J. Cook, Ph.D.....Board Member  
Raymond Y. Demers, M.D.....Board Member  
David T. Long, Ph.D.....Board Member  
Ronald H. Olsen, Ph.D.....Board Member  
Bette J. Premo, Ph.D.....Board Member  
Eileen O. van Ravenswaay, Ph.D.....Board Member  
George T. Wolff, Ph.D.....Board Member

**MICHIGAN ENVIRONMENTAL SCIENCE BOARD STAFF**

Keith G. Harrison, M.A., R.S., Cert. Ecol...Executive Director  
Shirley B. Willis.....Administrative Officer  
Sharon Picard.....Financial Officer  
Sandra Anderson.....Secretary

Michigan Environmental Science Board  
Lewis Cass Building  
P.O. Box 30026  
Lansing, Michigan 48909  
517-373-4960

**MERCURY  
IN  
MICHIGAN'S ENVIRONMENT:**

**ENVIRONMENTAL AND HUMAN HEALTH CONCERNS**

**(A Science Report To Governor John Engler)**

**Prepared by  
Michigan Environmental Science Board  
Mercury Panel**

**MICHIGAN ENVIRONMENTAL SCIENCE BOARD  
LEWIS CASS BUILDING  
P.O. Box 30026  
LANSING, MICHIGAN 48909**

**APRIL 1993**

**(THIRD PRINTING)**



*Copyright © 1993 by the Michigan Environmental Science Board  
State of Michigan, P.O. Box 30026, Lansing, Michigan 48909  
All Rights Reserved*

*Manufactured in the United States of America*

*Copies of this report may be obtained free of charge by  
writing to the Michigan Environmental Science Board*

|                                  |                   |                   |
|----------------------------------|-------------------|-------------------|
| <i>1st Printing April 1993</i>   | <i>310 Copies</i> | <i>\$1,333.00</i> |
| <i>2nd Printing May 1993</i>     | <i>200 Copies</i> | <i>\$ 860.00</i>  |
| <i>3rd Printing October 1993</i> | <i>200 Copies</i> | <i>\$ 860.00</i>  |

*Printed by Authority of Executive Order 1992-19*

**Correct Report Citation:**

Fischer, L.J., J.W. Bulkley, R.J. Cook, R.Y. Demers, D.T. Long, R.H. Olsen, B.J. Premo, E.O. van Ravenswaay, G.T. Wolff and K.G. Harrison. 1993. Mercury in Michigan's Environment: Environmental and Human Health Concerns, April 1993. Michigan Environmental Science Board, Lansing. xiii + 144p.

## TABLE OF CONTENTS

|   | Page |
|---|------|
| Preface.....  | vii  |
| Executive Summary.....  | ix   |
| Introduction.....   | 1    |
| Directive #1. Compile Existing Data and Estimate Risks.....                         | 3    |
| Existing Mercury Data for Michigan.....   | 3    |
| Human Health Risks from Mercury.....  | 3    |
| Exposure.....   | 4    |
| Effects in Infants and Children.....  | 5    |
| Michigan Today.....   | 6    |
| Protection from Methylmercury Effects.....  | 7    |
| Conclusions .....   | 8    |
| Directive #2. Determine Sources and Pathways and Means of Exposure.....             | 11   |
| Natural Emissions of Mercury.....   | 11   |
| Mercury in the Atmosphere.....  | 12   |
| Gaseous Mercury.....  | 14   |
| Particulate Mercury.....  | 14   |
| Contributions from Michigan Sources.....  | 15   |
| Wet Deposition of Mercury in Michigan.....  | 16   |
| Dry Deposition.....   | 17   |
| Implications of Deposition Data.....  | 17   |
| Impact of Local Sources on Deposition.....  | 18   |
| Relationship Between Air Emissions and Lake Concentrations.....                     | 20   |
| Mercury in Aquatic Systems.....   | 21   |
| Mercury in Sediments.....   | 22   |
| Wildlife Exposure.....  | 37   |
| Human Exposure.....   | 37   |
| Conclusions .....   | 38   |
| Directive #3. Determine Standards, Abatement Programs and Proposed Regulations..... | 41   |
| Existing Federal Programs.....  | 41   |
| Proposed Federal Programs.....  | 41   |
| Clean Air Act.....  | 41   |
| Great Waters Study.....   | 41   |
| Mercury Study.....  | 42   |
| Utility Study.....  | 42   |
| National Institute of Environmental Health Sciences Study.....                      | 43   |
| Other Federal Programs.....   | 44   |
| Agency for Toxic Substances and Disease Registry....                                | 44   |
| The Clean Water Act.....  | 44   |

|  |     |
|--|-----|
| The Great Lakes Water Quality Initiative.....  | 44  |
| Proposed Federal Legislation.....  | 44  |
| Existing State Programs.....   | 45  |
| Proposed State Legislation.....  | 46  |
| Regional Programs.....   | 47  |
| International Programs.....  | 48  |
| Other Programs.....  | 49  |
| Conclusions .....  | 49  |
| Directive #4. Propose and Evaluate Options.....  | 51  |
| General.....   | 51  |
| Latex Paint Emissions.....   | 52  |
| Waste Combustion.....  | 52  |
| Waste Separation and Recycling.....  | 54  |
| Combustion of Fossil Fuels.....  | 55  |
| Proposed Options for Controlling Mercury Emissions.....  | 56  |
| Recommendation #1.....   | 56  |
| Recommendation #2.....   | 56  |
| Recommendation #3.....   | 57  |
| Recommendation #4.....   | 57  |
| Recommendation #5.....   | 57  |
| Recommendation #6.....   | 57  |
| Recommendation #7.....   | 58  |
| Recommendation #8.....   | 58  |
| Directive #5. Recommend Further Study.....   | 59  |
| Water Quality and Biological Monitoring Needs.....   | 59  |
| Emissions and Air Quality Data Needs.....  | 60  |
| Human Monitoring Needs.....  | 60  |
| Education Needs.....   | 61  |
| Mercury Research Data Evaluation Needs.....  | 61  |
| References Cited.....  | 63  |
| Appendix I: August 6, 1992 Letter from<br>Governor John Engler.....                            | 73  |
| Appendix II: Michigan Environmental Science Board Mercury<br>Panel Annotated Bibliography..... | 77  |
| Appendix III: Draft Toxicological Profile for Mercury.....                                     | 127 |

### LIST OF TABLES AND FIGURES

|   | <u>Page</u> |
|---|-------------|
| Table 1. Concentrations of total gaseous mercury in Michigan and Chicago.....   | 14          |
| Table 2. Particulate mercury measurements in Michigan and Chicago.....  | 14          |
| Table 3. Estimated atmospheric deposition to the Great Lakes.....   | 17          |
| Table 4. Background concentrations of arsenic, cadmium, lead and mercury in soils and preliminary background values for sediments of the Great Lakes..... | 34          |
| Table 5. Mercury research projects currently underway by the Electric Power Research Institute.....   | 43          |
| Figure 1. Mercury concentrations in selected basins of Lake Superior.....   | 24          |
| Figure 2. Location map of inland lakes where metal sediment profiles were collected.....  | 25          |
| Figure 3. Inland lake mercury, lead and manganese sediment concentrations as a function of depth.....   | 27          |
| Figure 4. Background mercury concentrations in inland lakes.....  | 33          |
| Figure 5. Mercury enrichment factors in inland lakes.....   | 35          |
| Figure 6. Recent changes in mercury concentrations in inland lakes.....   | 36          |

## **PREFACE**

### ***Michigan Environmental Science Board***

The Michigan Environmental Science Board was created by Governor John Engler by Executive Order 1992-19 on August 6, 1992. The Board is charged with advising the Governor, the Natural Resources Commission, the Michigan Department of Natural Resources and other state agencies, as directed by the Governor, on matters affecting the protection and management of Michigan's environment and natural resources. The Board consists of 9 members, appointed by the Governor, who have expertise in one or more of the following areas: engineering, ecological sciences, economics, chemistry, physics, biological sciences, human medicine, statistics, risk assessment, geology and other disciplines as necessary. Upon the request of the Governor to review a particular issue, a panel, consisting of Board members with relevant expertise, is convened to evaluate and provide recommendations on the issue.

Dr. Lawrence J. Fischer  
Board Chairperson  
Michigan State University

Dr. Ronald H. Olsen  
Board Member  
University of Michigan

Dr. Jonathan W. Bulkley  
Board Member  
University of Michigan

Dr. Bette J. Premo  
Board Member  
White Water Associates, Inc.

Dr. Richard J. Cook  
Board Member  
Kalamazoo College

Dr. Eileen O. van Ravenswaay  
Board Member  
Michigan State University

Dr. Raymond Y. Demers  
Board Member  
Michigan Cancer Foundation

Dr. George T. Wolff  
Board Member  
General Motors

Dr. David T. Long  
Board Member  
Michigan State University

Mr. Keith G. Harrison  
Board Executive Director  
State of Michigan

**MERCURY IN MICHIGAN'S ENVIRONMENT:  
ENVIRONMENTAL AND HUMAN HEALTH CONCERNS**

**EXECUTIVE SUMMARY**

On August 6, 1992, the Michigan Environmental Science Board was charged by Governor John Engler to investigate the risks posed to Michigan's citizens by exposure to excessive levels of mercury, to determine the sources of mercury and the pathways by which it enters the environment and to propose and evaluate options for reducing the input of mercury to the environment.

A Panel, composed of the entire Board, was convened on September 11, 1992 to begin the project. The investigation consisted of the accumulation and evaluation of peer-reviewed and some non-peer-reviewed literature and data on the subject. In addition, verbal and written statements from experts, industry specialists and concerned citizens were considered. Major findings, conclusions and recommendations of the Panel are summarized below.

♦ The major non-point source of mercury in the Michigan environment is the atmosphere. Natural emissions are estimated to account for approximately 50% of mercury in the global atmosphere. Major natural sources of atmospheric mercury are microbial-mercury interactions in soils and sediments and degassing from the earth's crust. The fraction of mercury from natural sources (both from within and out of the state) that contribute to Michigan's atmosphere is unknown, but may be similar to the global average.

♦ The primary sources of atmospheric mercury that are derived from human activities in Michigan are waste incineration, coal combustion and latex paint usage (prior to 1990-91). Preliminary calculations indicate that human activities in Michigan may account for a relatively small percentage of mercury in the atmosphere over the state. This underscores the concern that mercury is more than a Michigan problem. It is a problem that is regional and, perhaps, global in scale.

♦ Mercury and particularly methylmercury are known to have toxic effects in humans, wildlife and other living systems. These forms of mercury and other forms in the environment are interconvertible in a series of complex and insufficiently understood processes. Accidental human poisonings involving methylmercury have shown it to cause harmful effects in the developing nervous system of the human fetus. The extent of methylmercury exposure to pregnant women associated with deleterious effects in their offspring have been estimated from accidental exposures. This information underscores the need to consider that pregnant women and particularly their fetuses are at special risk from mercury exposure.

♦ At this time it appears that the primary pathway for human exposure is consumption of fish containing mercury. Based upon known levels of mercury (which is mainly in the form of methylmercury) in Michigan sport fish, the rate of fish consumption by the population and the limited data bases on mercury levels in Michigan's population, and considering information regarding the known toxicity of methylmercury, there is not a demonstrable public health threat from methylmercury contamination in Michigan fish at this time.

♦ There is a lack of information about trends in mercury levels in Michigan fish. There is a potentially small margin of safety between background (i.e., natural) levels of mercury exposure and concentrations that can cause harm in humans. These factors add uncertainty to conclusions about the current health risk and preclude predictions regarding future health risks. Mercury must be taken seriously as a potential threat to public health and the environment.

♦ A reasonable and prudent strategy for managing mercury exposure and its associated risk, particularly in pregnant women and non-pregnant women of childbearing age would be to keep body burdens of mercury as low as possible. An assessment of the human health threat posed by mercury should be evaluated yearly by comparing current hair or blood concentrations of mercury in Michigan women with the lowest concentrations believed to produce deleterious effects in the offspring of exposed pregnant women.

♦ Considering the previous points, fish advisories for mercury should continue. The current advisories for restricting consumption of mercury-containing fish should be re-evaluated to determine if they are based on valid estimates of mercury intake for persons consuming freshwater fish.

♦ Recently enacted and proposed federal and state legislative initiatives and regulatory programs are anticipated to be successful in helping to reduce the input of mercury derived from human activities into the Great Lakes environment. In addition, recent agreements among the Great Lakes states and between the United States and Canada should also help to focus and coordinate many of the Great Lakes states' efforts to control and reduce additional inputs in the Great Lakes region. As a consequence of recently enacted programs at all levels of government, human-derived mercury emissions to the air should decrease.

♦ Michigan has the ability to reduce its contribution to atmospheric mercury within the Great Lakes region. Given this, and in light of the potential human health threat which can result from local as well as regionally derived mercury in the environment, Michigan should take necessary steps to reduce controllable mercury emissions within its borders. Panel recommendations to reduce emissions include:

1. Requiring state-of-the-art emission controls on existing and proposed municipal waste incinerators;
2. Implementing collection/recycling programs;
3. Developing stricter regulations for, or elimination of uncontrolled sources of solid waste combustion;
4. Requiring input and emission limits as a permit condition for existing and proposed facilities that incinerate hazardous wastes; and
5. Obtaining better information regarding the amounts and forms of mercury from coal-fired power utilities in order to determine the most appropriate and effective control options to be required.

These actions should be tied, if possible, into regional, national and global efforts. Along with mandatory programs, voluntary initiatives also should be encouraged.

♦ During the investigation numerous gaps were noted in the general knowledge base for mercury, particularly information related to Michigan. These gaps include the abundance, transport and fate of mercury in the Michigan environment; current levels and trends of mercury exposure of Michigan citizens and mercury emission rates from Michigan. Panel recommendations to close these information gaps include the following strategies:

1. Research should be encouraged and supported to evaluate the role of the Michigan terrestrial ecosystem in the transport and fate of mercury;
2. Levels of mercury in fish should be monitored in a manner that allows estimation of mercury contamination trends as a function of time and distance from sources;
3. The Michigan population, particularly those segments of society at higher risk, such as women of childbearing age, should be monitored to determine current levels and trends (time and distance) of mercury exposure;
4. The mercury exposure level at which there are harmful effects on humans should be re-evaluated yearly by the Michigan Department of Public Health with consideration of not only mercury exposure in Michigan's population, but also of acquired information from research from around the world;
5. Michigan should require utilities and other potentially significant sources of airborne mercury to test for the



amounts and forms of mercury in their emissions so that accurate emissions inventories can be created;

6. A central repository should be established in Michigan to collect and maintain the information obtained from the above efforts as well as any other related regional, federal or international studies or initiatives; and
7. The accumulated mercury information should be periodically reviewed and evaluated to provide the basis for future recommendations to the Governor on advancements in the understanding of the impacts of mercury on the environment and human health.

**MERCURY IN MICHIGAN'S ENVIRONMENT:**

**ENVIRONMENTAL AND HUMAN HEALTH CONCERNS**

**(A Science Report to Governor John Engler)**

## INTRODUCTION

The Michigan Environmental Science Board was created by Governor John Engler by Executive Order 1992-19 on August 6, 1992. The Board is charged with advising the Governor, the Natural Resources Commission, the Michigan Department of Natural Resources and other state agencies, as directed by the Governor, on matters affecting the protection and management of Michigan's environment and natural resources. The Board consists of 9 members, appointed by the Governor, who have expertise in one or more of the following areas: engineering, ecological sciences, economics, chemistry, physics, biological sciences, human medicine, statistics, risk assessment, geology and other disciplines as necessary. Upon the request of the Governor to review a particular issue, a panel, consisting of Board members with relevant expertise, is convened to evaluate and provide recommendations on the issue.

On August 6, 1992, the Board was charged by Governor Engler to investigate the risks posed to Michigan's citizens by exposure to excessive levels of mercury, to determine the sources of mercury and the pathways by which it enters the environment, and to propose and evaluate options for controlling or eliminating harmful emissions of mercury from the environment (see Appendix I).

A Panel, composed of the entire Board, was convened on September 11, 1992 to begin the project. The investigation consisted of the accumulation and evaluation of peer-reviewed and some non-peer-reviewed literature and data on the subject. In addition, verbal and written statements from experts, industry specialists and concerned citizens were considered. The report was prepared by subcommittees comprised of various Panel members with each subcommittee assigned a specific topic to address. The investigation lasted for a period of 8 months.

The report addresses 5 specific directives from the Governor:

1. Compile existing data regarding the levels of mercury found in Michigan's environment and estimate the risk those levels pose to the health of Michigan's citizens;
2. To the extent possible, determine the sources of mercury found in Michigan's environment, the pathways by which mercury enters the environment and the means by which humans are exposed to mercury;
3. Determine what state, federal and international standards and abatement programs currently exist, and the status of any proposed state or federal regulations;
4. Propose and evaluate options for controlling or eliminating harmful emissions of mercury into the environment; and
5. Recommend what further studies may be needed in order to implement the above charges.

**DIRECTIVE #1.** Compile existing data regarding the levels of mercury found in Michigan's environment and estimate the risk those levels pose to the health of Michigan's citizens.

### ***Existing Mercury Data for Michigan***

An excellent summary of the levels of mercury in the environment was prepared previously by the Michigan Department of Natural Resources (MDNR 1992c). In addition, Appendix II presents an annotated bibliography which has been compiled by the Michigan Environmental Science Board (MESB) Mercury Panel on the subject. In general, Michigan-specific data on the existing levels of mercury found in the state's environment are scant at best. What is known about the levels of mercury in the state's air, water, soil and biota has had to be supplemented with (at times, possibly controversial) data from investigations from outside of the state. Even with this, several critical data gaps persist; most notably, good data on speciating air concentrations, precipitation, soils, sediments and surface water quality, and trend data on air concentrations, precipitation, soils, sediments, lakes and fish. Other impediments to the determination of what levels of mercury currently exist have been a lack of complete information on the nature and processes involved in mercury cycling in the environment and a lack of complete information on all the processes involved in the combustion of mercury-containing material and the form of the mercury emissions.

In the discussions that follow, the MESB Mercury Panel has attempted to address the environmental and human concerns about mercury using the best and most recent data available. Areas where the Mercury Panel could not speculate, due to an incomplete or inadequate data base, are so noted. Also noted are those areas where additional research would be useful to close the existing data gaps.

### ***Human Health Risks from Mercury***

There are insufficient data pertaining to the past and current body burdens of mercury in Michigan's citizens for use in determining with certainty the risks of adverse health effects. Given the current level of knowledge concerning mercury exposure and toxicity, it can be estimated that a public health threat from mercury does not exist in Michigan at this time. However, the lack of knowledge needed to project future mercury levels in subpopulations having the highest sensitivity to the harmful effects of the most toxic form of the chemical (i.e., methylmercury) leaves open the possibility of future unacceptable

health risks. To fill these knowledge gaps requires that monitoring for mercury exposure in humans be undertaken on a regular basis. In addition, steps should be taken to reduce exposure until this new information is collected and analyzed.

**Exposure.** Mercury in various forms is found in air, water, soil and food. All of these environmental media may be involved in human exposure to elemental mercury and mercury-containing compounds. The primary and most common source of exposure to mercury is consumption of fish containing methylmercury (Turner et al., 1980; Clarkson, 1990; Humphrey, 1974). The extent of contamination of fish with methylmercury varies widely and depends on factors such as species and age of fish, natural characteristics of the aquatic environment and rate of mercury input to the water. Methylmercury, formed primarily by bacterial action in mercury-containing sediments, accumulates in the aquatic food chain and may reach high concentration in the muscle tissue of predatory fish (D'Itri, 1991).

Ocean fish and freshwater fish may contain methylmercury at concentrations that are of concern. Michigan has placed the level of concern at 0.5 ppm and above while the federal standard is 1.0 ppm. Most ocean fish purchased in stores contains less than 0.5 ppm of mercury. For example, tuna sampled by the Florida Department of Agriculture has been found to contain an average of 0.3 ppm (range 0.13 ppm to 0.76 ppm) (Fong, 1993). Shark meat is of current concern because it has been consistently found in many states to be above 1.0 ppm. Shark purchased in Michigan stores has recently been found to contain between 1.0 ppm and 2.6 ppm (MDA, 1992). Swordfish can contain similar high levels of methylmercury but U.S. Food and Drug Administration (FDA) testing has been effective in not letting violative products get to the market (Schneider, 1993).

Certain species of freshwater fish (e.g., northern pike) from Michigan's waters occasionally have been found to contain levels of mercury above 1.0 ppm but the average concentration calculated from all fish sampled in 166 lakes since 1987 contained less than 0.5 ppm (Hesse, 1992). Ingestion of fish containing methylmercury results in complete absorption of methylmercury into the blood and it is distributed to most tissues of the body (WHO, 1990). Mercury and methylmercury concentrate in hair and quantitative assessment of exposure can be obtained from analysis of blood or hair samples. Methylmercury is eliminated from the body by metabolism and excretion and these processes are rapid enough to limit accumulation in the body even though exposure is continuing (Clarkson, 1990). Thus, methylmercury does not have the same properties that permit more persistent chemicals such as DDT, PCBs and TCDD to accumulate in the body over a long period of time.

Accidental and/or occupational exposure to high amounts of mercury in its elemental, inorganic or organic forms can result in human

toxicity (D'Itri, 1991). These intoxications are relatively rare and often preventable by applying personal and institutional-based safety precautions. Given the infrequent nature of these poisonings and reasonable possibilities for their prevention, consideration of these high dose exposures are not included in this report.

Data acquired by the Michigan Department of Public Health (MDPH) in the early 1970's indicated that consumption by anglers of mercury-contaminated fish (walleye) from Lake St. Clair was associated with increased body burdens of methylmercury (Humphrey, 1974). Blood levels of mercury were low (in the background range, about 5 ppb) in individuals who did not consume fish and increased with increasing fish consumption. Three persons consuming over 70 pounds per year of fish had blood levels averaging 78 ppb. In the same study, levels in fish consumers in South Haven, Michigan, where fish contamination with methylmercury was less than in Lake St. Clair, had lower blood levels of mercury. Seven high consumers of Lake Michigan fish (>70 lbs./yr) had an average blood mercury level of 15 ppb. These data are consistent with results published in the scientific literature indicating that fish consumption is a primary exposure route for mercury in the human population.

The blood levels of mercury in humans obtained by the MDPH apply to specific locations in Michigan 20 years ago and are probably not applicable to the situation that exists in Michigan today. For example, monitoring results indicate levels of mercury in fish from Lake St. Clair have declined by greater than 50% over the past 15 years (Hesse, 1992). This resulted from elimination of point sources of pollution that existed in the early 1970's. Today's mercury problem generally does not result from point sources but may instead be caused by atmospheric deposition of mercury; a process which has a wider impact on Michigan's inland lakes than mercury from point sources.

**Effects in Infants and Children.** There is a scientific consensus regarding the high sensitivity of the developing fetal nervous system to the harmful effects of methylmercury. The concept of high fetal sensitivity to methylmercury is derived from laboratory animal studies (Elsner et al., 1988; Bornhausen et al., 1980) and from human poisonings in Iraq and Japan (Marsh et al., 1987; Harada, 1966). The unusually large amount of data on methylmercury effects in the human population greatly reduces the need to depend on laboratory animal data to estimate human dose-response relationships.

Pregnant women represent the most susceptible subpopulation to toxicity resulting from methylmercury exposure. Data obtained from accidental methylmercury poisonings which occurred in Iraq in the 1970's have shown that infants born to highly exposed mothers exhibit permanent symptoms of damage to the central nervous system (Marsh et al., 1987). Information obtained from 80 mother-infant

pairs permit an estimation of the amount of mercury in the body of pregnant women that may be associated with these harmful effects in infants. A sophisticated mathematical analysis of the data to estimate the shape of the exposure-response curve suggests that harmful effects occur when maternal hair levels (an index of the amount of mercury in the body) are above 10 ppm to 20 ppm (Cox et al., 1989).

The World Health Organization (WHO) has adopted the range of 10 ppm to 20 ppm mercury in hair as the threshold for the harmful effects of methylmercury (WHO, 1990). Because a small number of children from mothers having hair mercury in this range were studied in Iraq, the threshold range is uncertain but its use is considered a reasonable and prudent health precaution. The advantage of the data from Iraq is that it was obtained from human poisonings that did not involve other toxic substances. In addition, a clear relationship between extent of exposure, measured by mercury levels in maternal hair, and degree of neurological alteration in children is apparent in the data. While it is not certain that adverse effects in children were observed between 10 ppm and 20 ppm mercury in maternal hair, it is clear from the Iraq data reported by Marsh et al. (1987) that adverse health effects occurred at higher levels of methylmercury (i.e., >100 ppm) in maternal hair.

Several other studies of children from mothers exposed to methylmercury during pregnancy have been evaluated for use in determining the threshold for adverse effects. Studies in Native American (McKeown-Eyssen et al., 1983) and New Zealand fisheating populations (Kjellstrom et al., 1989) were not considered to be as informative as the data from Iraq. Studies in Japan of children exposed during the Minamata poisoning incident indicate that harmful effects can be seen at massive exposures but do not provide an opportunity to examine the threshold exposure for methylmercury effects. Currently, studies are underway in children from fisheating populations in the Seychelle Islands (Indian Ocean) and the Faeroe Islands (north of Denmark). These studies, funded by U.S. National Institutes of Health, will not be complete for 3 or more years (Fouts, 1993). It is hoped that they will provide data that will complement the information from Iraq and refine the threshold value for effects of methylmercury on the developing human fetus.

**Michigan Today.** The information available at this time indicates that Michigan's population is not being subjected to a health risk from methylmercury. From past results, it is calculated that the highest rate of consumption (>70 lb/yr) of contaminated fish (>1.25 ppm of mercury) would produce maternal hair levels of approximately 20 ppm which is at the WHO (1990) estimated threshold for adverse effects in the fetus. Estimated body burdens from more usual consumption rates (e.g., 48 lbs/yr or less) are not associated with hair levels in the range for health concerns. Because average contamination levels of methylmercury in fish from Michigan's lakes

are well below those previously observed in Lake St. Clair, it can be estimated that there is little chance, with average to high consumption of fish, that current mercury exposure is yielding a verifiable and unacceptable health threat. However, without knowing whether the levels of methylmercury in fish from Michigan's waters are increasing, decreasing or are constant at this time, it is not possible to predict whether a health threat will exist sometime in the future.

Swain and Helwig (1989) have estimated that mercury levels in fish from Minnesota's inland lakes may be increasing at a rate of about 0.02 ppm/year. This estimate is made from very limited data but if it were true for Michigan fish it would take approximately 20 years for high consumers of fish to experience unacceptable body burdens of mercury. Women of childbearing age in particular would experience an unacceptable risk based upon our knowledge today regarding methylmercury effects in the fetus.

**Protection from Methylmercury Effects.** While it is believed that methylmercury exposure to Michigan's population does not adversely impact public health at this time, it is recommended that the state take action to help ensure that effects of the chemical do not occur in the future. Mercury exposure deserves special concern because it has been demonstrated to cause neurobehavioral deficits in children born to exposed pregnant women. Mercury levels in the blood of Michigan adults who do not consume large amounts of fish may be only ten-fold lower than those calculated to have possibly produced adverse effects in children born to methylmercury exposed women in Iraq. This estimate is based on a comparison of the lowest maternal exposure levels that were associated with harmful effects in Iraqi children (WHO, 1990) with Michigan exposures based on blood mercury analysis in adults having low (or no) fish consumption (Humphrey, 1974). The estimate that potentially harmful blood concentrations of mercury may be only ten-fold higher than those in Michigan adults having relatively low mercury exposures from fish consumption indicates a relatively small margin of safety for methylmercury exposure. This situation may be a general characteristic of exposure to toxic heavy metals such as mercury, lead, cadmium and nickel.

The margin of safety for mercury appears relatively low compared to those for many human-derived (anthropogenic) environmental pollutants. It appears inappropriate to apply the usual safety factor approach to risk management for mercury. To illustrate, application of a safety factor of 10 ppm to the currently estimated WHO (1990) exposure threshold of 10 ppm to 20 ppm in maternal hair would place nearly the entire population of the state in the unacceptable exposure range because background levels of mercury in hair can be expected to be between 1 ppm and 5 ppm (D'Itri, 1991). A similar situation, indicating unacceptable mercury exposure values in the background range, occurred when safety factors were applied to calculate an acceptable daily intake (ADI) of 0.07



µg/kg/day by a New Jersey task force on mercury emissions (NJDEPE, 1992). The current ADI recommended by the U.S. Environmental Protection Agency (USEPA) is 0.3 µg/kg/day. Dr. Thomas Clarkson, a renowned expert on mercury toxicology, has recommended that safety factors not be used in the calculation of the ADI for mercury (Clarkson, 1990; 1991).

Rather than application of safety factors to calculate acceptable exposure to mercury compounds, the threshold for its effects should be determined using results from the best information available stressing results from human epidemiology studies. In addition, mercury exposure should be monitored in the Michigan population to determine current body burdens and trends for change. Exposure in the most sensitive population subgroup, pregnant women, must be kept below that determined to produce harmful effects. Risk management performed by state agencies should attempt to keep mercury body burdens as low as is feasible given economic and social restraints. These mitigating restraints should be identified and reported by the state agencies conducting risk management for mercury.

### ***Conclusions***

Based on the preceding discussion, the following conclusions may be drawn regarding the risk to human health from mercury:

- ♦ The Michigan population, particularly pregnant women, should be monitored periodically and in a scientific manner to determine the current level of exposure and whether exposure is changing. Hair and/or blood concentrations of mercury in the sensitive population should be measured at intervals not exceeding 5 years.
- ♦ The threshold exposure for methylmercury effects (currently 10 ppm to 20 ppm in hair) should be reevaluated on a yearly basis by the MDPH. This will permit the incorporation of newly acquired information that will increase the accuracy of the threshold estimate.
- ♦ A yearly evaluation of mercury exposure in Michigan's population in relation to the most current threshold exposure value for methylmercury effects should take place. This evaluation will provide an estimate of current and projected health risks.
- ♦ Advisories for restricting consumption of mercury contaminated fish should continue. The advisories should be developed using data obtained from a scientifically sound monitoring program in Michigan which will provide valid estimates of mercury intake for persons consuming freshwater fish from its waters. The monitoring program should also be designed to estimate the rate of change of mercury contamination in fish. Statistical and sampling consulta-

tion should be sought by state agencies because the current method of monitoring may not be able to provide valid estimates of the current level of fish contamination or of its rate of change. The fish consumption advisories should be consistent with current risk estimates for adverse health effects from methylmercury based heavily, but not entirely, on effects in the offspring of exposed pregnant women. Advisories should be changed to reflect changes in exposure estimates calculated from monitoring mercury levels in fish and humans.

♦ Steps should be taken in conjunction with other states in the Great Lakes region to limit the emission of mercury into the environment. The extent and intensity of these regulatory actions should be linked to valid indices of contamination levels determined, at least in part, from monitoring fish and human exposure.

**DIRECTIVE #2.** To the extent possible, determine the sources of mercury found in Michigan's environment, the pathways by which mercury enters the environment and the means by which humans are exposed to mercury.

### ***Natural Emissions of Mercury***

Natural global emissions of mercury to the environment are equal to or, perhaps, greater than anthropogenic emissions (Fergusson, 1990). The global anthropogenic emission rate for mercury is estimated to be  $649.7 \times 10^6$  g/year and the global natural emission rate is estimated to be  $1,018.5 \times 10^6$  g/year. Although these estimates are highly uncertain, it appears that natural emissions account for about 50% of the total. Thus, even if anthropogenic emissions of mercury were eliminated, there would likely still be significant natural sources of mercury to the environment. Natural emissions of mercury occur via biological and physical mechanisms.

Both organo-mercury compounds and mercury salts (mercury-two) are toxic to microbial activities, growth and reproduction. Perhaps as a consequence of the occurrence of these compounds, bacteria have adapted to the presence of mercury in their environments by developing adaptive biochemical mechanisms to detoxify mercury to its elemental form mercury-zero (Summers 1986). This adaptation by a wide range of microorganisms with disparate metabolic properties and ecological niches has been observed for many bacteria which abound in both the soil and aquatic environments (Silver and Misra, 1988). From such observations it can be deduced that a volatile form of mercury (mercury-zero) may occur in natural emissions associated with microbial activities in these environments. This facilitates wide natural distribution of mercury-zero throughout the environment from contamination that originated as point source pollutants. Moreover, exposure to mercury increases the incidence of mercury transformation activity (i.e., resistance) in both soil and water bacterial populations (Moser and Voight, 1957) as well as in the oral and intestinal flora of primates (Summers et al., 1990). If the notion of wide dispersion of mercury-zero in the atmosphere is accepted, then it is conceivable that inland aquatic environments may accumulate mercury-zero wherein it may be transformed to methylmercury. Methylmercury is a toxic form known to bioaccumulate in fish and animal tissues and therefore be ingested by human populations. In aqueous environments, under oxidative conditions (i.e., non-reducing conditions), mercury-zero is in equilibrium with mercury-two by chemical dismutation (Moser and Voight, 1957). Furthermore, mercury-zero may exist in sediments under reducing conditions as mercuric sulfide.

The methylation of mercury may occur by 3 possible mechanisms: (1) photochemical (abiotic), (2) methylation of mercury-two by methylcobalmin acting as a methyl donor by bacteria which excrete this compound or (3) by a flora of aquatic microorganisms perhaps

utilizing methylcobalmin (Summers and Silver, 1987). The biological methylation of mercury has been demonstrated under anaerobic conditions by bacteria in river and lake sediments as well as by cell-free extracts of methanogenic bacteria (Jensen and Jernelov, 1969; Olson and Cooper, 1976). More recently, when methylmercury formation was studied with whole sediment communities, sulfate reducers were found to carry out this activity and, contrary to expectations, specific inhibition of methogens stimulated methylation (Compeau and Bartha, 1985).

In addition to the possible cycling of mercury reflecting ongoing biological processes suggested above, significant amounts of mercury are released from the earth's crust, due to natural degassing. Such emissions increase the mercury available for biological transformation(s) and the accumulation of methylmercury in aqueous environments and their sediments.

### ***Mercury in the Atmosphere***

Methods to accurately measure mercury in the ambient air were only developed in the early to mid-1980's, and this complex methodology was not used to analyze samples collected in Michigan until 1991 when Dr. Gerald Keeler from the University of Michigan School of Public Health began to use it (Lamborg et al., in press). For this reason, and because the methodology is very tedious and labor-intensive, the Michigan data base is short and sparse. This means that nothing can be deduced from the data about trends in ambient concentrations in Michigan. However, its consistency with data bases collected elsewhere in the U.S., allow, with reasonable confidence, some generalizations about spatial patterns.

Methylmercury is the form of mercury that concentrates in the food chain. Most of the methylmercury that is in fish is thought to be formed from the oxidized form, mercury-two, that is present in the water body. The major source of most of the mercury-two in the inland lakes in Michigan appears to be atmospheric deposition. According to crude estimates made in Great Lakes region, wet deposition accounts for about 60% and dry deposition about 40% of the total deposition (Eisenreich and Strachan, 1992). However, only 10% to 30% of the mercury in precipitation appears to be reactive mercury-two. Most of the rest is an unreactive form that is thought to be organic (Keeler, 1993). It is not known how this form is formed or if it contributes to the methylmercury in the fish. In the atmosphere, mercury exists in several different chemical forms and it is not certain which form(s) is (are) the precursor(s) to mercury-two in the precipitation and dry deposition. In addition, there is much uncertainty concerning the sources of the possible precursors.

In the atmosphere, 95% to 99+% of the mercury usually exists as gaseous, elemental mercury-zero (Lamborg, in press; Keeler et al., in press). Other forms observed in the atmosphere include an

oxidized particulate form, particulate mercury-two, an unreactive particulate form, particulate mercury, gaseous methylmercury, and, perhaps, dimethylmercury. Although it has not been detected in the atmosphere away from sources (Lindqvist, 1991), the existence of gaseous mercury-two (most likely mercuric chloride) cannot be ruled out, especially in the vicinity of sources. The mercuric chloride has unusually high volatility for a metal chloride with its condensation curve indicating that at ambient temperatures and at dilute concentrations, the compound could exist in the gaseous state (Mayer-Schwinning and Laibold, 1989). The gaseous mercury-zero is a candidate as a precursor of the mercury-two in the precipitation simply because it is by far the dominant form in the atmosphere. The particulate mercury-two is thought to occur primarily in the submicron size range, although substantial amounts are sometimes seen in the coarse fraction (Keeler, 1993), and is thought to be primarily mercuric chloride. This and the gaseous mercury-two are candidate precursors because they are water soluble.

The unreactive particulate mercury form is thought to be tightly bound to coarse crustal material and is not a mercury-two precursor candidate because it is unreactive. However, it may be related to the unreactive fraction in the precipitation. Although gaseous methylmercury has been detected by some researchers, the concentrations appear to be too low to contribute appreciably to the mercury-two in the precipitation. Consequently, of the species that exist in the atmosphere, only gaseous elemental mercury-zero, particulate mercury-two, and gaseous mercury-two are considered candidates as precursors of mercury-two in the precipitation.

As mentioned above, although gaseous mercury-two has not been reported in the ambient air, measurements made in the stacks of incinerators and coal-fired boilers have detected it in significant amounts. It is thought to be gaseous mercuric chloride. Since particulate mercury-two, not gaseous mercury-two, has been detected in the atmosphere, it is possible that the gaseous mercury-two, which is emitted at high temperature, condenses on existing particles to form particulate mercury-two in the atmosphere. However, the rate at which this transformation occurs is not known, but it is extremely important because the spatial deposition patterns of gaseous mercury-two and particulate mercury-two are different. To complicate matters further, there is some evidence that mercury-two is reduced by sulfur dioxide in power plant plumes to gaseous mercury-zero.

The most important constituent of the particulate phase is thought to be a submicron, acid-soluble fraction, which is dominated by mercury-two and probably exists primarily as mercuric chloride. Another fraction, which is inert, occurs primarily in the supermicron size range and appears to be associated with wind blown soil. Because of its inertness, it is unlikely that it could be converted to methylmercury, so it has been largely ignored by researchers.

**Gaseous Mercury.** Measurements of total gaseous mercury in Michigan and vicinity are shown in Table 1. Measurements made in remote areas of the world average about 2 ng/m<sup>3</sup>, which is similar to values measured in South Haven, Lake Michigan and Ann Arbor. However, the higher concentrations at the larger urban areas, especially at Detroit 01, strongly suggest a significant enhancement due to local sources. In addition, since the Lake Michigan and South Haven sites were sometimes downwind of Chicago, the data suggest that this enhancement from urban emissions does not exist very far downwind of the source areas. It should be noted, that even at the relatively high concentrations experienced in the urban areas, they are still several orders of magnitude below the concentrations that would be of a health concern from an inhalation route.

Table 1. Concentrations of total gaseous mercury in Michigan and Chicago.

| Location      | N  | Mean<br>(ng/m <sup>3</sup> ) | Maximum<br>(ng/m <sup>3</sup> ) |
|---------------|----|------------------------------|---------------------------------|
| South Haven   | 38 | 2.0                          | 4.3                             |
| Lake Michigan | 25 | 2.3                          | 4.9                             |
| Ann Arbor     | 10 | 2.0                          | 4.4                             |
| Detroit 05    | 10 | 3.7                          | 8.5                             |
| Detroit 01    | 10 | >41.0                        | >70.0                           |
| Chicago       | 58 | 8.7                          | 62.7                            |

Source: Keeler (1993); Lamborg et al. (in press); Hoyer et al. (1993).

**Particulate Mercury.** The concentrations of particulate-phase, acid soluble mercury in Michigan are summarized in Table 2.

Table 2. Particulate mercury measurements in Michigan and Chicago.

| Location      | N  | Mean<br>(pg/m <sup>3</sup> ) | Maximum<br>(pg/m <sup>3</sup> ) |
|---------------|----|------------------------------|---------------------------------|
| South Haven   | 18 | 18.6                         | 29.0                            |
| Lake Michigan | 9  | 28.4                         | 54.0                            |
| Ann Arbor     | 10 | 100.0                        | 300.0                           |
| Detroit 05    | 10 | 297.0                        | 1230.0                          |
| Detroit 01    | 10 | 342.0                        | 1086.0                          |
| Chicago       | 16 | 97.5                         | 518.0                           |

Source: Keeler (1993); Lamborg et al. (in press); Hoyer et al. (1993).

The mean concentrations measured at the South Haven and Lake Michigan sites are in the range of measurements made in rural/remote areas which suggests they may be representative of background levels. The much higher concentrations in the urban areas, including Ann Arbor, indicate that there are local sources which increase the concentrations ten-fold or more.

**Contributions from Michigan Sources.** The MDNR (1992c) estimates that there are 37,000 pounds of anthropogenic mercury emitted into Michigan's atmosphere per year. Cole et al. (1992) estimates this figure to be 18,000 pounds per year. The uncertainty in these estimates is large and not quantifiable, but they are probably the correct order of magnitude which is sufficient to estimate how much of the observed ambient concentrations can be attributed to these emissions.

Using the higher MDNR (1992c) emission rate and assuming that (1) the area of Michigan is 60,000 square miles, (2) the emissions are injected and mixed homogeneously into the lower 5,000 feet of the atmosphere and (3) the air mass in Michigan has a residence time of 1 day, then the total air volume would equal  $2.3 \times 10^{14} \text{ m}^3$  and the 37,000 pounds per year emission rate would correspond to a daily rate of  $4.6 \times 10^{13} \text{ ng}$ . As a consequence, the concentration due to Michigan emissions would equal  $0.2 \text{ ng/m}^3$ , which is only 10% of the  $2 \text{ ng/m}^3$  observed in the rural areas. This means that either the anthropogenic emissions are grossly underestimated, there are large natural sources, previously deposited mercury cycles back and forth between terrestrial and aquatic sinks, and/or most of the mercury observed in Michigan is transported into the state. Because the  $2 \text{ ng/m}^3$  value has been established as the background concentration based on measurements in a number of remote locations in the Northern Hemisphere (Slemr and Langer, 1992), it is likely that the bulk of the mercury is transported into Michigan. The natural contribution, however, is an open issue. Estimates of natural emissions are highly uncertain but are generally the same order of magnitude as the anthropogenic sources on a global basis. However, little is known about the magnitude of natural sources in Michigan. Moreover, it is likely that some of the mercury, emitted from either anthropogenic activities or natural sources and subsequently deposited on the earth's surface, revolatilizes and contributes to the observed concentrations. The residence time of gaseous elemental mercury in the atmosphere has been estimated to be on the order of 1 year and the effective lifetime could be considerably longer if significant amounts of mercury are revolatilized.

Evidence that revolatilization is occurring include: the seasonable behavior of gaseous mercury, the excellent correlation of gaseous mercury and temperature and the vertical profile of gaseous mercury. Growing season gaseous mercury concentrations were found to be about twice as high as dormant season concentrations in Tennessee (Lindberg et al., 1991). At the same locations, Lindberg et al. (1991) found a strong positive correlation ( $r^2 = 0.59$ ) of

gaseous mercury with air temperature. At 2 sites, in Tennessee and Washington, where vertical profiles of mercury were measured, gaseous mercury concentrations decreased with height (Lindberg et al., 1991; Lindqvist, 1991). Collectively, these observations suggest that gaseous mercury is volatilizing from the ground and that the net flux is positive at least during the summer when these profiles were measured. The fact that the gaseous mercury concentration tracks ambient temperature so well implies that the ground must be a net sink at other times. Recent measurements made by Lindberg (1993) confirm this and suggest that the net flux from the ground is near zero. This underscores the importance of characterizing the life cycle of mercury in the environment and determining the ultimate fate of mercury emissions.

**Wet Deposition of Mercury in Michigan.** For the past year, Keeler (1993) has been analyzing precipitation samples collected in Ann Arbor, South Haven and Pellston, Michigan. Concentrations of mercury in the precipitation at all 3 sites average about 12 ng/l, which compares to a background range of 2 ng/l to 10 ng/l (Lindberg et al., 1991). The mercury in the rain is dominated by mercury-two (Lindqvist, 1991). So the important question is how does mercury-two dominate in the precipitation, while gaseous elemental mercury dominates in the air. There are 2 ways that this can occur. Either the gaseous elemental mercury is oxidized in the droplet or particulate or gaseous mercury-two is the source of the mercury in precipitation (or a combination of the two).

The evidence for gaseous mercury-zero as a candidate precursor is as follows. The mean concentration of gaseous mercury-zero in rural areas is around 2 ng/m<sup>3</sup>. At this concentration, at 5°C, Henry's Law predicts that the concentration of mercury in the rain should be  $11 \times 10^{-3}$  ng/l (Schroeder et al., 1991). This is 3 orders of magnitude lower the average of about 12 ng/l observed in Michigan (Keeler, 1993). This means that either gaseous mercury-zero does not contribute to the mercury in the precipitation or that gaseous mercury-zero rapidly reacts within the droplet to form mercury-two. One of the many potential reactions is with ozone. Iverfeldt and Lindqvist (1986) estimated that in a cloud containing 1 g of liquid water per cubic meter of air, 13 ppb of ozone, and 1 ng/m<sup>3</sup> of elemental mercury, the rate of oxidation of the mercury will be about 1% per hour. Such a rate could account for a significant part of the mercury-two in the rain, but probably not all of it, and only in liquid clouds. Such a mechanism would not occur in frozen precipitation. However, there may be other oxidation mechanisms, but none as important as the ozone have been identified.

The primary sources of mercury-two are combustion sources. If the mercury-two condenses onto existing particles, it will end up primarily on accumulation mode particles with a mean diameter of about 0.5 µm. Such particles are efficiently removed by nucleation scavenging but not by washout. Consequently, the mercury-two



particles will be efficiently removed within the cloud, but the concentration of mercury-two particles below the cloud will be relatively unaffected. A liquid water concentration of 1 g/m<sup>3</sup> of air and a particulate mercury-two concentration of 20 pg/m<sup>3</sup> corresponds to a rain concentration of 20 ng/l if 100% of the mass was scavenged. Typically, nucleation scavenging removes 75% to 95% of the mass (Warneck, 1988) which would correspond to a concentration of 15 ng/l to 19 ng/l. This compares to the average of 12 ng/l observed at the sites in Michigan. Consequently, this mechanism may account for all of the mercury observed in the precipitation.

The water-soluble gaseous mercury-two will also be efficiently incorporated into a forming or falling droplet or snow flake. However, since its concentration in the ambient air is not known, the importance of this mechanism cannot be assessed, but it could be significant especially in the vicinity of a large gaseous mercury-two source.

**Dry Deposition.** Total deposition in rural Wisconsin has been estimated to be 10 µg/m<sup>2</sup> to 15 µg/m<sup>2</sup> per year. About 70% of this is estimated to be from wet deposition and 30% from dry deposition (Fitzgerald et al., 1992). Recent data from the Great Lakes region (see Table 3) show total deposition values to be of the order of 26 µg/m<sup>2</sup> to 29 µg/m<sup>2</sup> per year with about 40% due to dry deposition (Eisenreich and Strachan, 1992).

Table 3. Estimated atmospheric deposition to the Great Lakes (µg/m<sup>2</sup>/yr).

| Lake     | Wet deposition | Dry deposition | Total deposition |
|----------|----------------|----------------|------------------|
| Superior | 15.2           | 11.34          | 26.54            |
| Michigan | 15.8           | 11.34          | 27.14            |
| Huron    | 15.2           | 11.34          | 26.52            |
| Erie     | 16.8           | 11.34          | 28.14            |
| Ontario  | 17.8           | 11.34          | 29.14            |

Source: Eisenreich and Strachan (1992).

Because of the recent data discussed above suggesting that the ground may actually be a net source of airborne mercury, caution should be used concerning the dry deposition estimate. In any event, wet deposition appears to be a more important deposition route.

**Implications of Deposition Data.** Whether in-cloud oxidation or nucleation scavenging of particulate mercury-two, washout of gaseous mercury-two or a combination are responsible for the deposition of mercury-two, there are important implications

concerning control strategy options. If in-cloud oxidation dominates, then the control strategy would focus on reducing the elemental mercury. However, the effectiveness of a Michigan-only strategy would be severely limited because Michigan emissions may only contribute on the order of 10% or less to the observed levels in the state. The 10% is probably an upper limit because of the conservative assumption that the mercury is only mixed into the lower 5,000 feet of the atmosphere. In reality, it is probably mixed into the entire troposphere (height averages about 37,000 feet) because the residence time of elemental mercury in the atmosphere has been estimated to be on the order of 1 year. Consequently, even if all of the anthropogenic emission sources of mercury were eliminated in the state, a 10% reduction in deposition may be an upper limit. It is obvious, that if in-cloud oxidation dominates, a national, continental or hemispheric control strategy would be needed to significantly reduce mercury deposition in Michigan.

If nucleation scavenging of particulate mercury-two or washout of gaseous mercury-two dominates, Michigan may have a little more control over its own destiny if Michigan emissions account for a significant fraction of the airborne mercury-two. Based on existing emissions data, however, nothing can be stated about what fraction of the airborne concentrations of mercury-two can be attributed to sources in Michigan. Mean concentrations of particulate mercury-two in rural areas of Michigan and Wisconsin appear to be between 20 pg/m<sup>3</sup> and 30 pg/m<sup>3</sup> (although concentrations as high as 1,230 pg/m<sup>3</sup> have been observed in Detroit) (Keeler, 1993; Fitzgerald et al., 1991). If the average concentration is 30 pg/m<sup>3</sup>, this corresponds to 15% of the estimated anthropogenic mercury emissions in Michigan. Consequently, if only 15% of the estimated 37,000 pounds per year emitted in Michigan were in the form of particulate mercury-two or gaseous mercury-two, it would account for the average observed ambient concentrations of particulate mercury-two in rural Michigan. Consequently, there is a good chance that reducing particulate mercury-two and/or gaseous mercury-two emissions in Michigan will have an impact on deposition. Nevertheless, deposition decreases can be expected to be less than proportional to mercury-two emission reductions because the lifetime of particles of this size or water soluble gases in the atmosphere is on the order of 1 week. As a result, a significant fraction of the observed concentrations is imported into Michigan.

**Impact of Local Sources on Deposition.** The impact of a source on deposition of mercury in the vicinity of the source could effect the immediate area by enhancing the dry and wet deposition of mercury. If the form of the mercury emission is known, the additional dry deposition can be estimated using traditional dispersion modeling and published dry deposition velocities. However, dry deposition of elemental mercury is not expected to be important because of its low dry deposition velocity and the

likelihood of substantial revolatilization.

Wet deposition modeling is in a much more primitive stage especially with respect to in-cloud chemical transformations. However, from first principles, the magnitude of the enhanced wet deposition can be assessed. If in-cloud oxidation is the primary mechanism, then local enhancement will be negligible. The limiting reactant in the in-cloud oxidation is the oxidant, which, in this case, ozone is thought to be the most important oxidant. Falling raindrops through a concentrated plume containing mercury-zero and combustion emissions will encounter mercury-zero molecules in the plume. However, unless there are high concentrations of an oxidant to rapidly oxidize the mercury, the mercury-zero will volatilize from the droplet. Within the plume in the vicinity of a combustion source, ambient ozone is rapidly depleted by reaction with nitric oxide, a ubiquitous by-product of combustion processes. Therefore, within the plume the emitted mercury will not encounter the additional ozone required to oxidize it, so it will revolatilize from the droplet. Consequently, enhanced wet mercury deposition would not be expected in this case.

The impact of a significant source on local deposition depends on how fast the gaseous mercury-two is converted to particulate mercury-two (see previous discussion on mercuric chloride volatility). Because gaseous mercury-two has not been observed in the atmosphere far from sources, it appears that the gaseous mercury-two condenses onto existing particles to form particulate mercury-two as the plume cools and mixes with ambient air. Maximum dry deposition will occur downwind of the source at the point where the plume reaches the ground. By the time this occurs the gaseous mercury-two may have already converted to primarily submicron particulate mercury-two. Because submicron particles are not efficiently removed by dry deposition, the incremental increase in total mercury deposition should be minimal. In addition, because of the variable nature of the wind speed and direction, the location where the plume reaches the ground will vary considerably.

Submicron particles are also inefficiently removed by washout. However, given the high concentration within the plume initially, some of the particles will be scavenged by falling droplets or snow flakes even though the process is very inefficient. More importantly, however, gaseous mercury-two will be scavenged efficiently. Consequently, there will be an enhancement of the wet mercury deposition under the plume. Given this scenario, the maximum enhancement will occur in the vicinity of the stack, with the effect diminishing downwind in proportion to the decreasing gaseous mercury-two concentration in the plume as it disperses. Deposition would be decreased further if the gaseous mercury-two is converted to particulate mercury-two. Overall, a negligible amount of particulate mercury-two will be removed in this manner. Most of the remaining particles will be removed downwind by nucleation scavenging. However, for that to happen, the particles must be

incorporated into a cloud. That will likely not occur until the plume has dispersed and mixed throughout the mixed layer. The zone of enhanced wet deposition due to washout has been observed by Greenberg et al. (1992) around a municipal resource recovery facility. Data collected during 3 precipitation events showed a zone of enhanced mercury wet deposition extending out to about 1 km. Additional measurements are needed to characterize the spatial extent of the zone.

Ambient air measurements show that at the rural sites near Lake Michigan and at most of the time in Ann Arbor total airborne mercury concentrations are near the levels considered to be global background in the Northern Hemisphere. In Detroit and Chicago, higher concentrations of total mercury due to local emissions are evident, and in Ann Arbor, there is an enhancement of particulate mercury due to local sources.

There are no definitive data which allow a determination of how far downwind of the urban areas concentrations above background occur. Because the Lake Michigan site and the South Haven site were occasionally downwind of Chicago and because enhanced mercury concentrations were not observed at these two sites, the size of the geographic area influenced by the urban sources appears to be small. However, this is a question that needs to be further investigated.

**Relationship Between Air Emissions and Lake Concentrations.** Given that a portion of the mercury found in surface waters will be methylated and enter the food chain, a question that needs to be addressed is: are the observed deposition rates of mercury sufficient to account for the observed mercury in surface waters? Unfortunately, this question cannot be answered using data from Michigan's lakes because such a data base does not exist. However, if it is assumed that the concentrations in Michigan lakes are similar to lakes in Minnesota and Wisconsin where mercury concentrations in precipitation are similar, then the answer to the question would be yes. The concentrations in the lakes average about 2 ng/l while the average concentration in the precipitation is 12 ng/l (Keeler, 1993). This means there is more than enough mercury present in the precipitation to account for the mercury in the surface waters.

The next question is then: are the observed ambient air mercury concentrations sufficient to account for the observed concentrations of mercury-two in the precipitation? The answer to this question is also yes, and, as explained in the section on Wet Deposition of Mercury in Michigan, there are two possible mechanisms. The mercury-two in the precipitation can be accounted for by scavenging of the mercury-two, by a combination of scavenging and in-cloud oxidation of gaseous elemental mercury, but probably not in-cloud oxidation of elemental mercury by itself.

The relative importance of the scavenging versus the in-cloud oxidation is important because it will influence the type of emission reduction strategy necessary to reduce mercury deposition.

A third question would be: are the estimated mercury emissions in Michigan sufficient to produce the observed airborne concentrations of elemental mercury and particulate mercury-two? A previous calculation demonstrates that estimated anthropogenic mercury emissions in Michigan can only account for about 10% of the observed total mercury concentrations in the ambient air in the state. Thus, if the in-cloud oxidation mechanism is the dominant mechanism, complete elimination of all the mercury sources in Michigan would reduce the amount of mercury deposited by 10% at best.

To determine whether there is sufficient particulate mercury-two emissions in Michigan to account for the mercury-two in the ambient air, it is important to know how much of the total mercury emissions is emitted in the form of mercury-two. Unfortunately, there are no speciation data available for Michigan's sources, and since the distribution between the elemental and oxidized forms is dependent on the chlorine content of the fuel and the type and configuration of the air pollution control equipment, the ratio is likely to vary considerably from facility to facility; even for the same type of source. Consequently, without data from each of the major sources, there is no way to definitely answer this question. However, since the observed concentrations in the non-urban areas would be accounted for if only 15% of the total mercury emissions were mercury-two, it seems likely that Michigan sources would account for a measurable fraction of the observed ambient mercury-two. If this is the case, then decreases in mercury deposition could be realized if there were reductions in mercury-two emissions within the state. The deposition reductions would be less than proportional, particularly on the upwind borders where wet deposition would be dominated by upwind states' emissions.

As a consequence of recent actions (i.e., banning mercury in latex paint, significantly reducing the mercury content of batteries, phasing out of the chloralkali industry, declining use of mercury, etc.), mercury emissions to the air should be decreasing in Michigan and the U.S. as a whole. Between 1986 and 1990, mercury use in the U.S. declined from 1,750 tons to 792 tons per year, and the trend continues (Cole et al., 1992). Therefore mercury deposition should be decreasing, and the observed mercury concentrations may be due partially to past rather than present emission levels.

### ***Mercury in Aquatic Systems***

Contaminants like mercury enter surface water via: (1) wet and dry deposition, (2) particle flux to sediment, (3) dissolved species exchange at sediment-water interface, (4) gas exchange at air-water

interface, (5) dissolved species and particle flux via rivers, (6) dissolved species from ground water to river runoff, (7) dissolved species direct discharge of ground water to lake and (8) gas exchange at soil-air interface. Some of these pathways involve the air-land-lake transfer of mercury. Rates of transfer appear to be increased by dissolved organic and colloidal carbon (Wiener et al., 1992; Lodenius, 1992; Johansson and Iverfeldt, 1992; Johansson et al., 1991). Mierle (1990) and Aastrup et al. (1991) have shown by mass balance study, that a significant amount of mercury deposited from the atmosphere may be retained in the terrestrial system. They also found that the amount of mercury retention differs among watersheds.

Once in the aquatic environment, mercury is variously compartmentalized into the water, the seston and the biota, and trapped in the sediments. Mercury that is most available to biota (e.g., zooplankton, insects and fish) is in the form of methylmercury. This is the form of mercury that is taken up by biota and bioaccumulates in the tissue (Watras et al., 1989).

The local environment of the aquatic system has a great deal to do with how much total mercury entering the system becomes the toxic methylmercury form (Lathrop et al., 1991, Hurley et al., in press). Current research indicates that biomethylation by sulfur bacteria is an important mechanism by which methylmercury is produced (Watras et al., 1989). The amount of biomethylation that occurs in a water body seems to depend on pH, alkalinity, state of anoxia, sulfur sources, dissolved organic material and other factors within the aquatic environment. The ratio of methylmercury to total mercury in the aquatic systems studied so far seems to range from approximately 0.1 to 0.3 (i.e., approximately 10% to 30% of total mercury is in the form of methylmercury). Total mercury in rural Wisconsin surface waters ranges from approximately 1 ng/l to 7 ng/l (Fitzgerald and Watras, 1989). There is currently very little information on measurements of mercury in Michigan's surface water or groundwater (MDNR, 1992c).

### ***Mercury in Sediments***

Sediment studies show that there may be a regional gradient in the natural emission of mercury. For example, the pre-industrial concentrations of mercury in the sediments of Lake Superior are 35.9 ng/g, 36.5 ng/g, 22.3 ng/g, and 10.5 ng/g going from the west to east in the lake. Such a gradient is consistent with the changes in the geology of the region going from west to east. In the west the geology is characterized by the Precambrian Shield which are rocks with relatively high mercury concentrations. In the east there is the Paleozoic sediments of the Michigan basin, which by comparison, are relatively low in mercury. The exact natural pathways for mercury in these environments are not known.

There has been a significant increase in the anthropogenic loading

of mercury to the environment (e.g., see Swain et al., 1992). However, from sediment research, the exact magnitude of this increase or the recent changes in this loading over the Great Lakes region is not known. The reason for this lack of knowledge is the effects of diagenesis on mercury concentrations in the sediments. Diagenesis is the chemical changes that take place in sediments once they are buried. The decay of organic matter causes the oxidation-reduction state of the sediment to decrease. This causes the dissolution of iron and manganese oxides in the sediments.

Iron and manganese oxides as well as organic matter are major scavengers of heavy metals. With the decay of organic matter and the dissolution of the oxides, mercury associated with these phases is released and can migrate within the sediment, out of the sediment, or be adsorbed at a different location in the sediment.

For example, Figure 1 shows mercury concentration profiles for sediments of Lake Superior. If it is assumed that the time frame when the anthropogenic mercury was input into the basin was relatively similar throughout the lake, then the age of the sediments where the beginning of the significant anthropogenic additions of mercury occurs should be similar throughout the lake. However, the figure shows that this is not true. The increase in mercury concentrations of recent sediments is tied to the location of the iron-manganese oxide layer. This layer is formed by the diagenetic reactions in the sediments. The conclusion here is that the increase in mercury concentrations is linked to diagenetic reactions and not anthropogenic inputs. In reality, the increase of mercury in the sediments is probably a combination of both. Some of the data that have been collected from the lakes indicate that well preserved historical records of mercury loadings to the lakes may exist.

Concentrations of mercury in sediments of Lake Michigan and Lake Superior have either been increasing at some sites or remaining the same at others. Although there appears to be a regional background concentration gradient for mercury, maximum and excess concentrations of mercury in the sediments of both lakes are similar. This implies that the addition of mercury to these lakes is from a regional (atmospherically dominated) source with a relatively uniform concentration. Thus, the atmospheric deposition of mercury appears to be relatively similar throughout the Great Lakes region. This means that the terrestrial system is receiving mercury loading to the same extent as the aquatic system.

Between 1987 and 1990, the MDNR collected lake sediment samples for purposes of analyzing metals concentrations (Evans et al., 1991; Evans, 1993). Twenty-three inland lakes with depths greater than 20 meters were chosen (Figure 2). An attempt was made to choose lakes that were deep enough to reduce problems of sediment resuspension and to provide data throughout the state. In addition

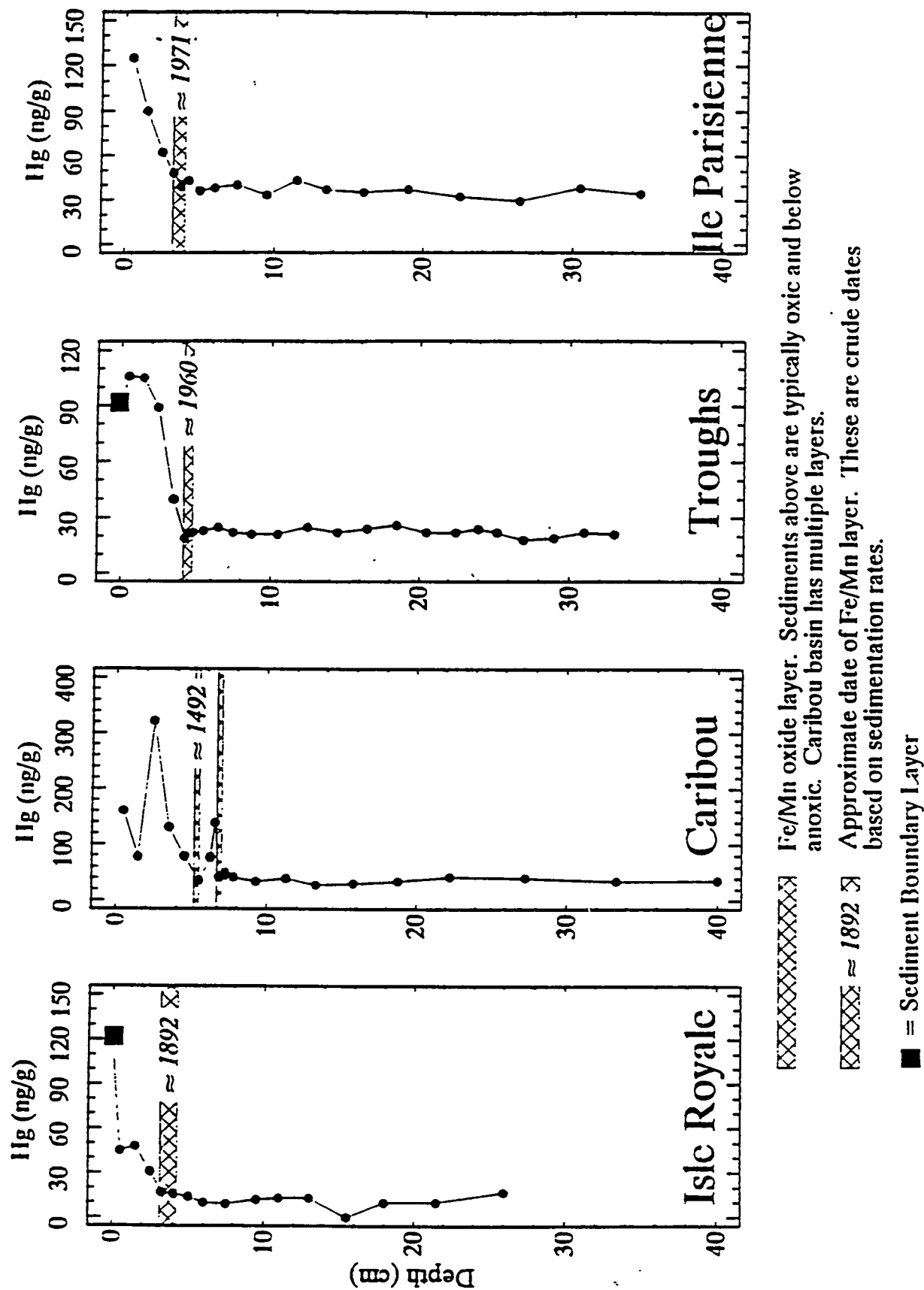


Figure 1. Mercury concentrations in selected basins of Lake Superior (From Strunk, 1991).



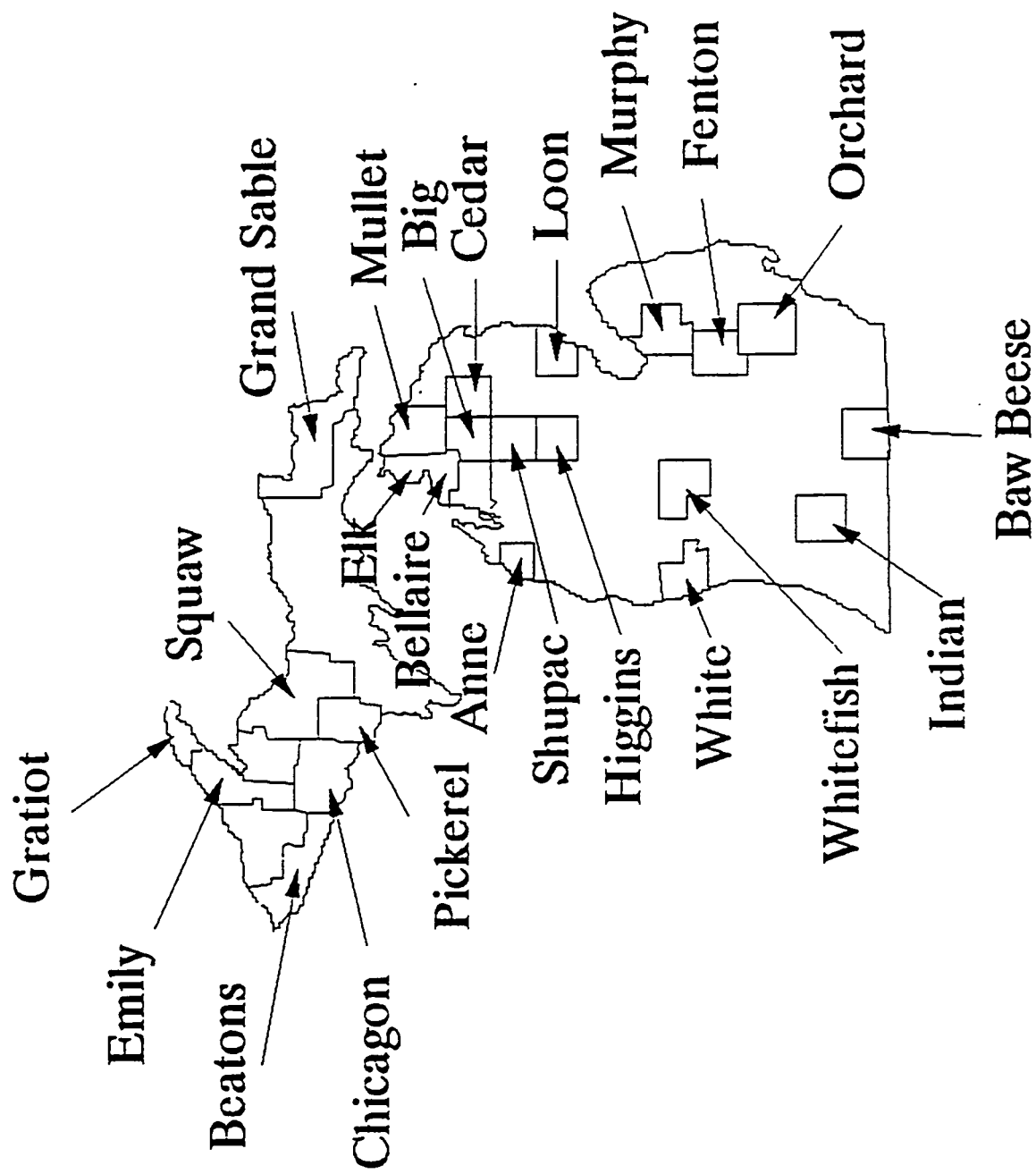


Figure 2. Location map of inland lakes where metal sediment profiles were collected; all lakes were greater than 20 m deep (from Long, 1993).

mercury concentrations in Lakes Superior and Michigan were analyzed.

Data from that study are presented in Figures 3-6 and Table 4 (Long, 1993). Mercury data were plotted as a function of depth in the sediments of the lakes (Figure 3). In addition, lead and manganese data were included for the inland lakes (Figure 3). Lead was included as an indicator of anthropogenic inputs, since the types of changes in the record of atmospheric lead loading to the Great Lakes region is known to have increased and then decreased to recent time. Manganese is included because it can be used as an indicator of diagenetic processes in the sediments that might affect the mercury profiles in the sediments.

The background concentrations of a metal in the sediments can be taken as the relative concentrations at depth in the sediments. The background values for mercury range from 18 ng/g to 110 ng/g and average 55 ng/g (Figure 4, Table 4). The background concentrations for the inland lakes in Michigan have a greater range of values and higher average than values in the sediments in the Great Lakes (Table 4). However, the average of 55 ng/g for the inland lakes does not appear to be significantly different from that of soils from around the U.S. The cause of the difference between background values in the sediments of the Great Lakes and inland lakes of Michigan is not known. Possible causes for the difference is the fate and transport of mercury in the terrestrial ecosystem and how that affects inland lakes. There may also be differences in the role of diagenesis between the Great Lakes and the inland lakes. There appears to be regional pattern in background values in the inland lakes. This may be due to differences in rock types throughout the state.

In all cases except one, mercury is enriched in the surface sediments compared to background concentrations at a particular lake (Figure 5). Enrichment factors (surface concentration/background concentration) range from 0.8 to 6.7. There appears to be regional patterns of enrichment of mercury in the sediments. The cause of the enrichment is a combination of increased anthropogenic inputs of mercury to the lakes and diagenetic processes.

Of the inland lakes studied, 13 lakes show concentrations of mercury in the sediments have been increasing, 3 lakes show concentrations have been decreasing and 7 lakes (although in most cases the near surface sediments are enriched in mercury compared to background values) show no recent changes in concentrations (Figure 6). However, sediments of the Great Lakes taken from depositional basins show that lead concentrations have been decreasing. Sediments of the Great Lakes taken from areas affected by bottom sediment erosion have incomplete lead records and typically show that lead concentrations are increasing. The cause of the increasing lead record (as well as mercury) in sediments of the inland lakes is unclear. It is possible that concentrations

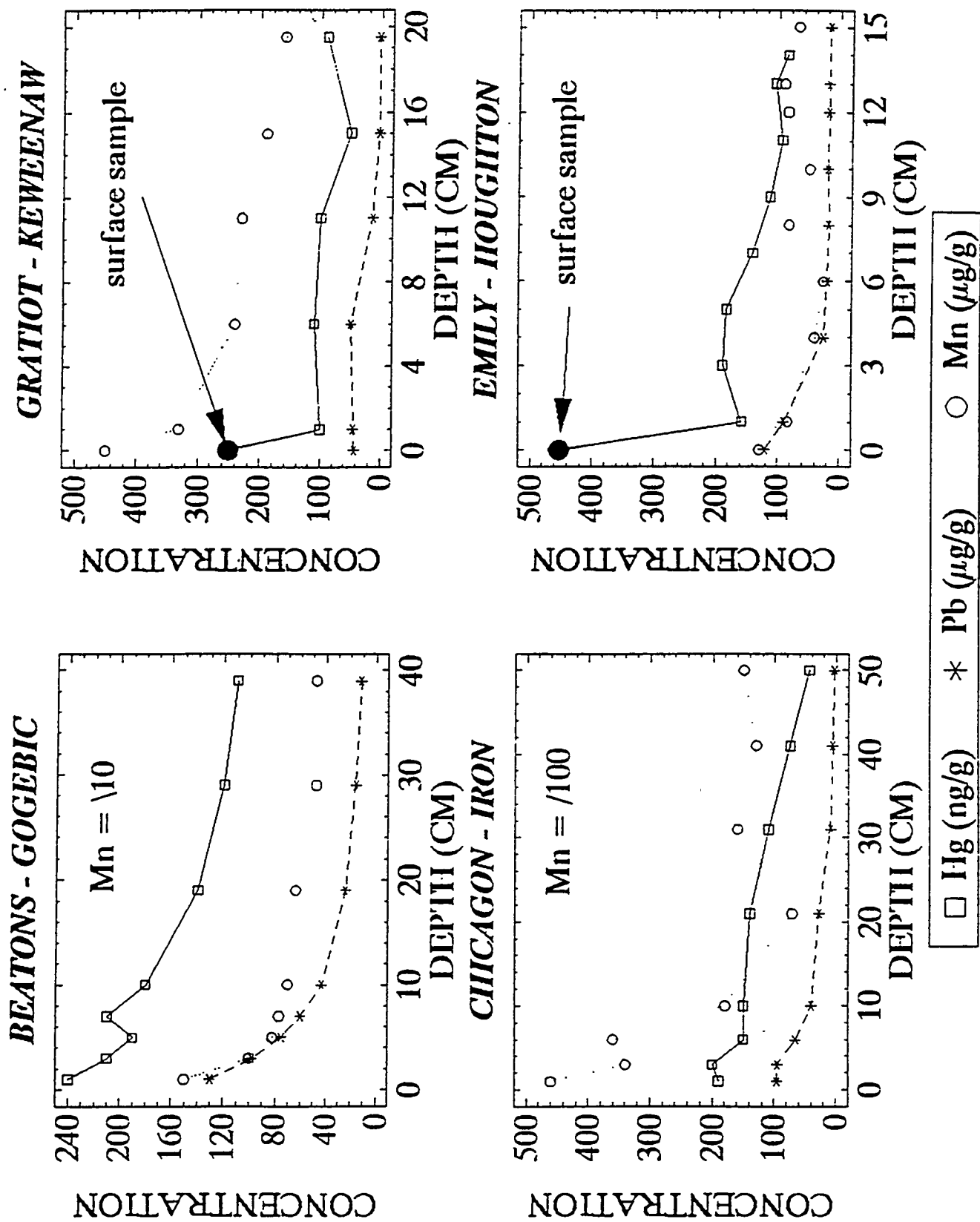


Figure 3. Inland lake mercury, lead and manganese sediment concentrations as a function of depth (from Long, 1993).

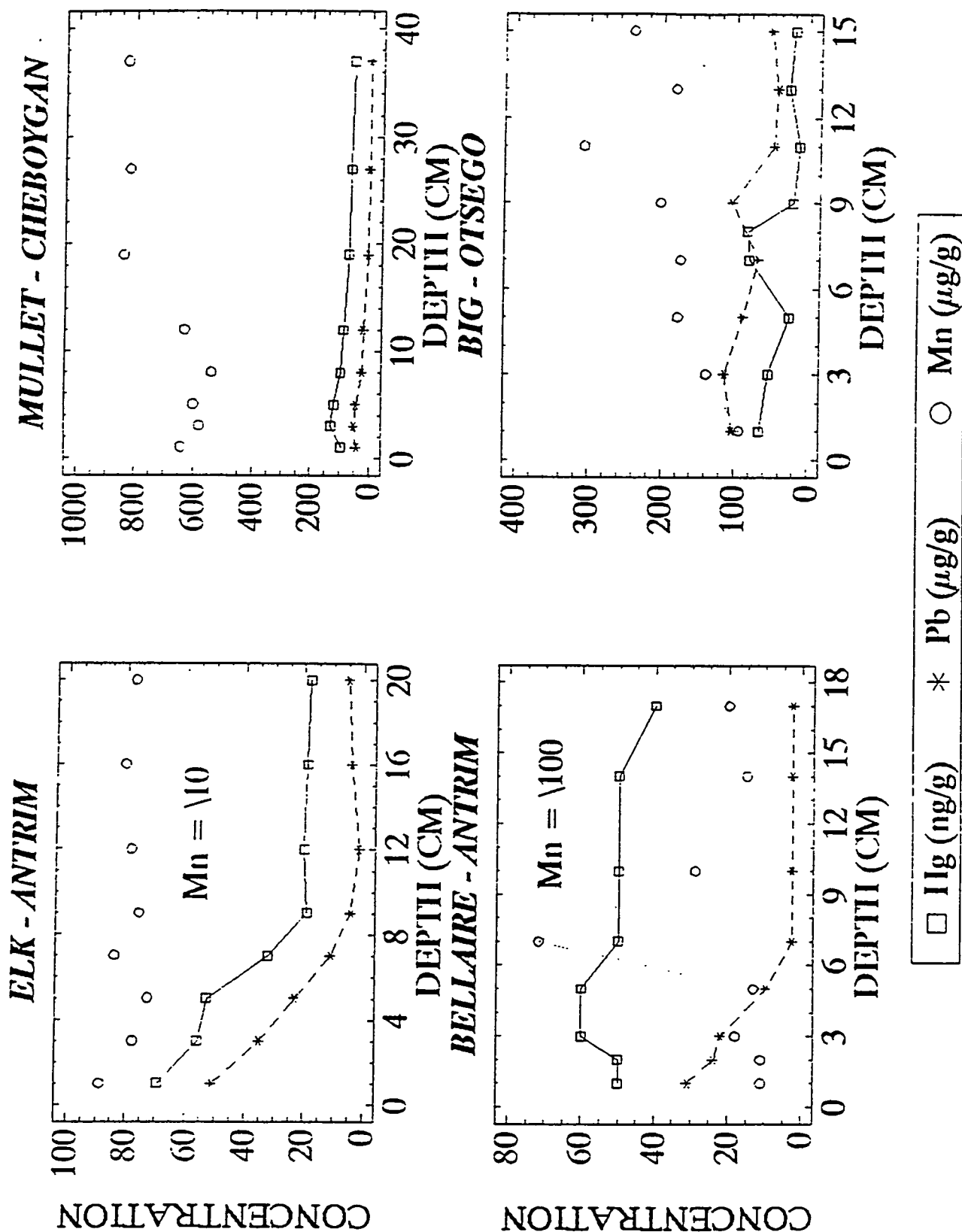


Figure 3. Inland lake mercury, lead and manganese sediment concentrations as a function of depth, continued.

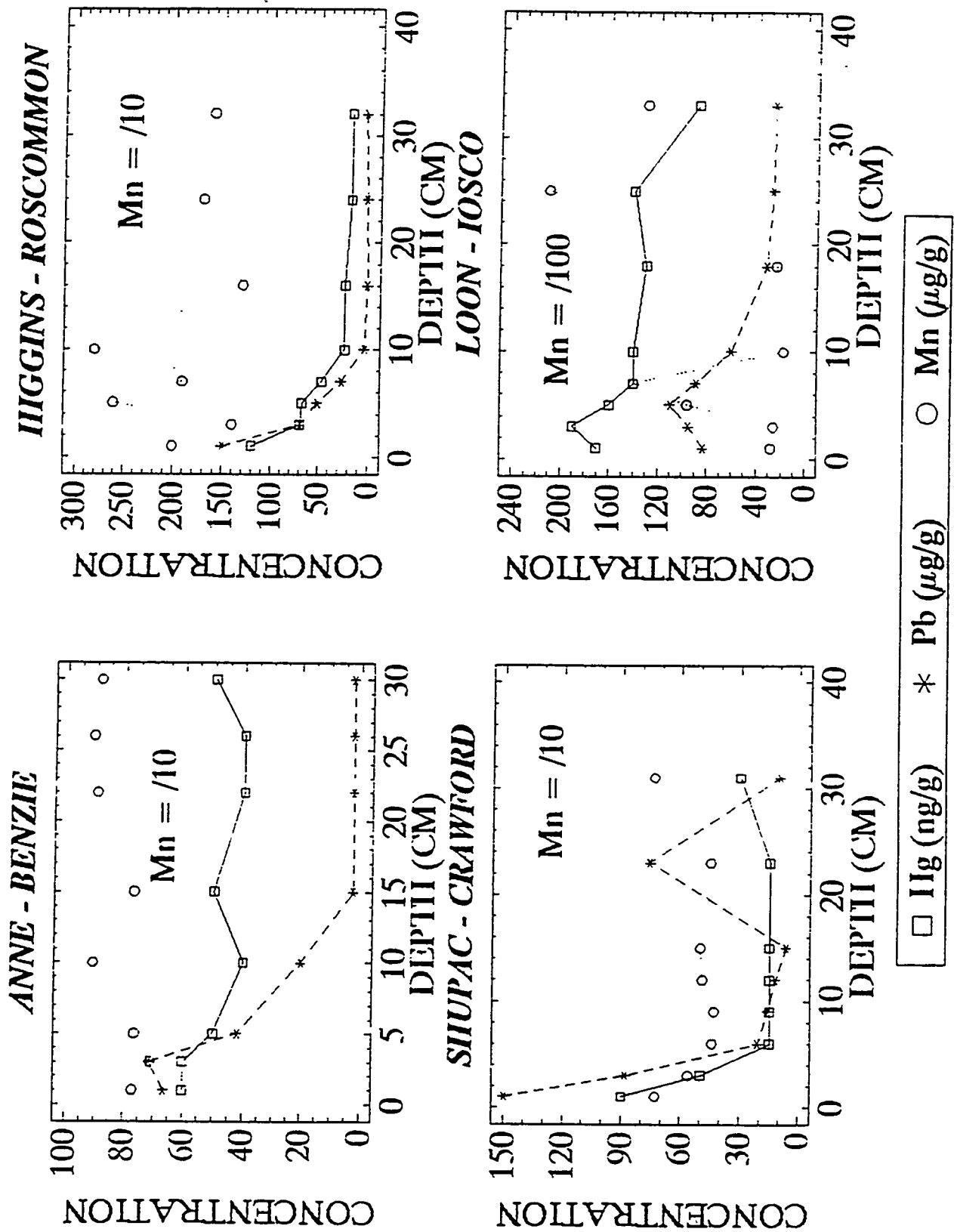


Figure 3. Inland lake mercury, lead and manganese sediment concentrations as a function of depth, continued.

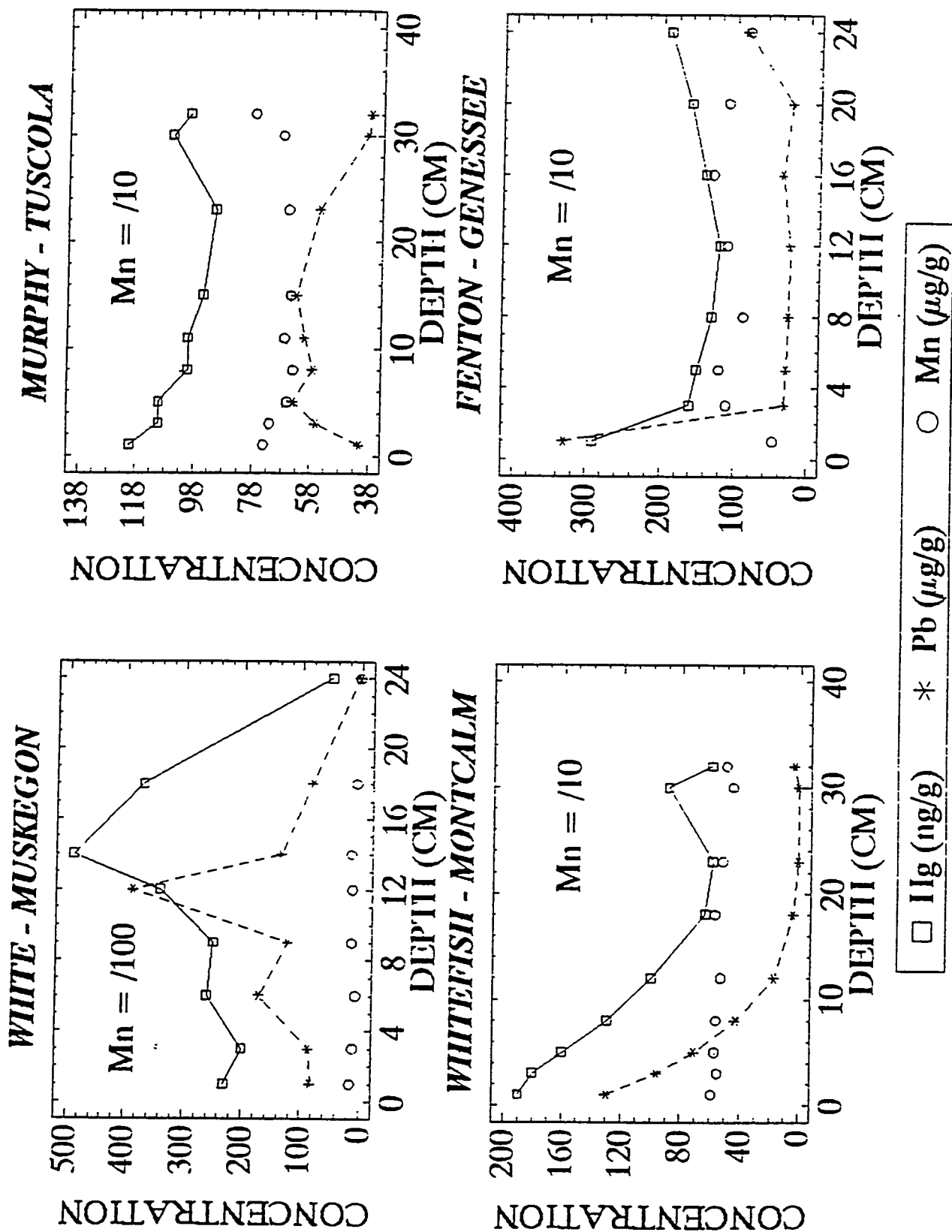


Figure 3. Inland lake mercury, lead and manganese sediment concentrations as a function of depth, continued.

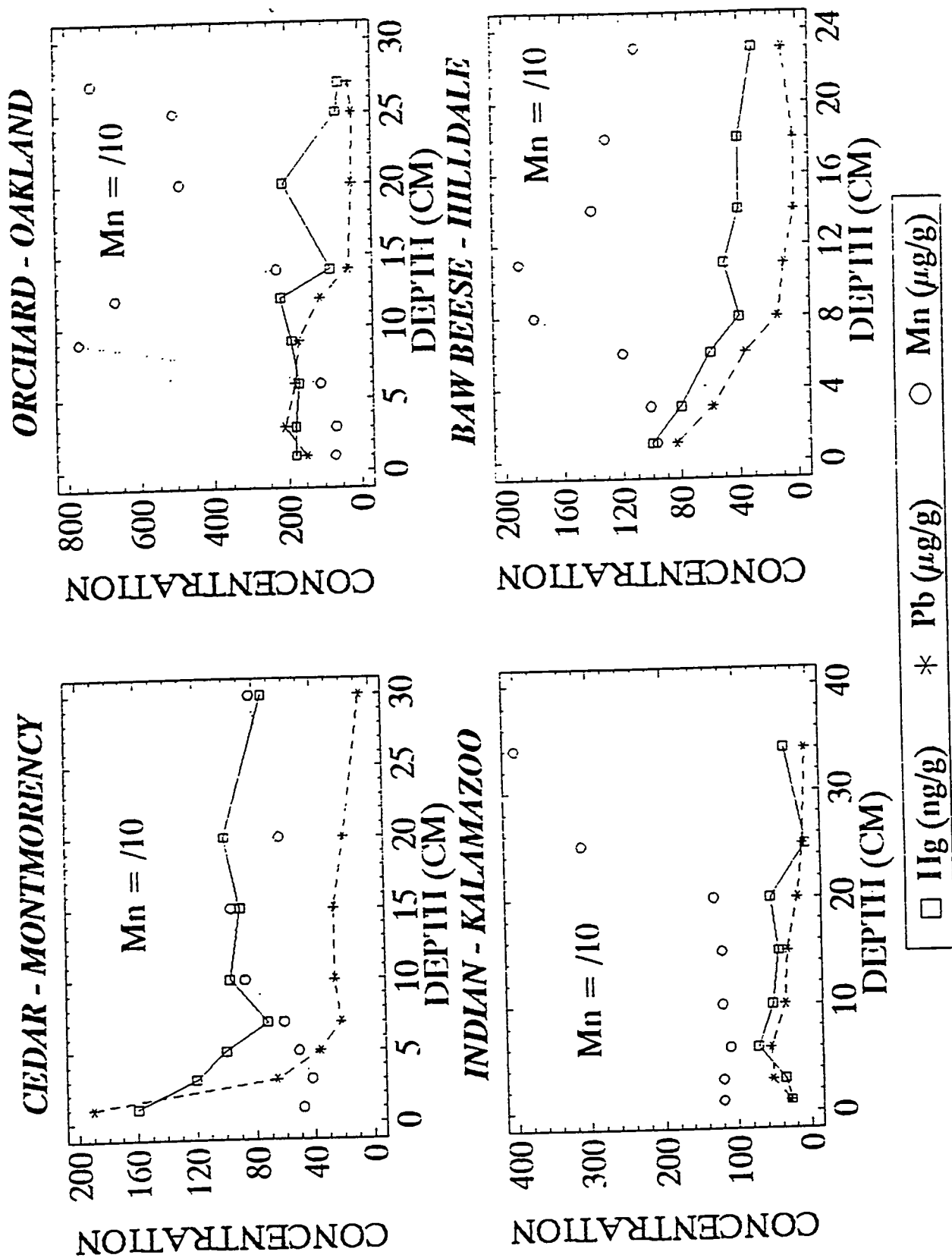


Figure 3. Inland lake mercury, lead and manganese sediment concentrations as a function of depth, continued.

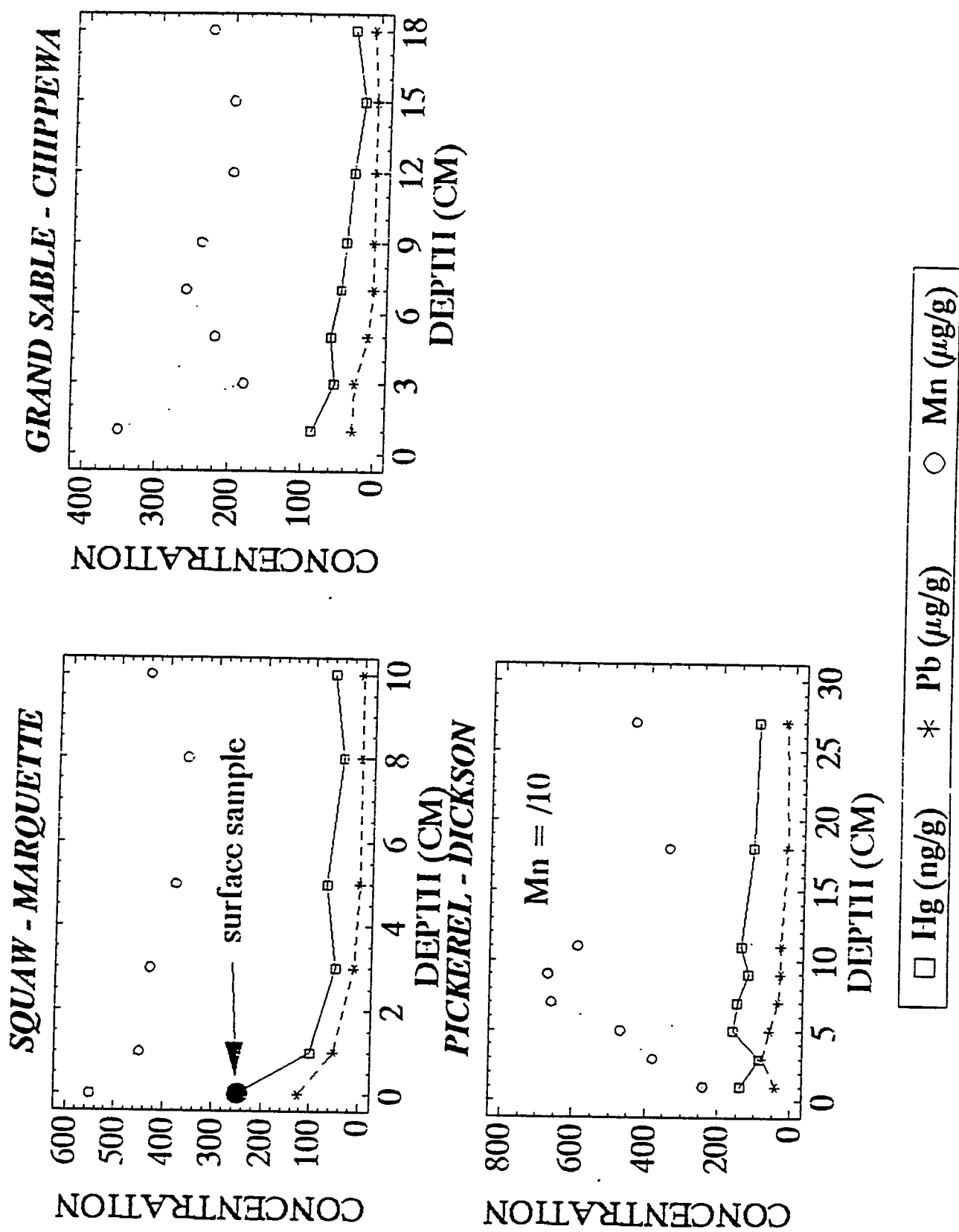
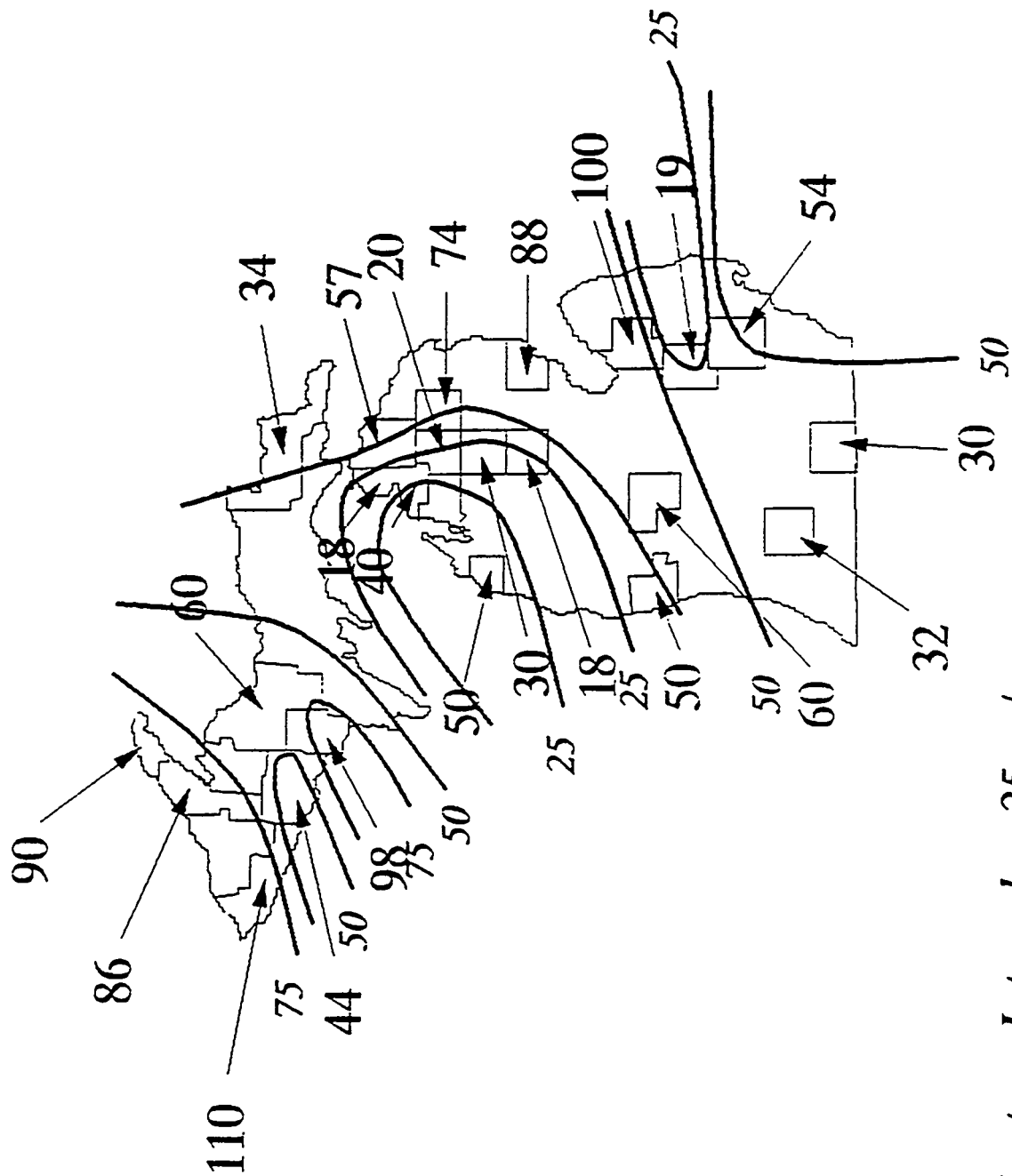


Figure 3. Inland lake mercury, lead and manganese sediment concentrations as a function of depth, continued.





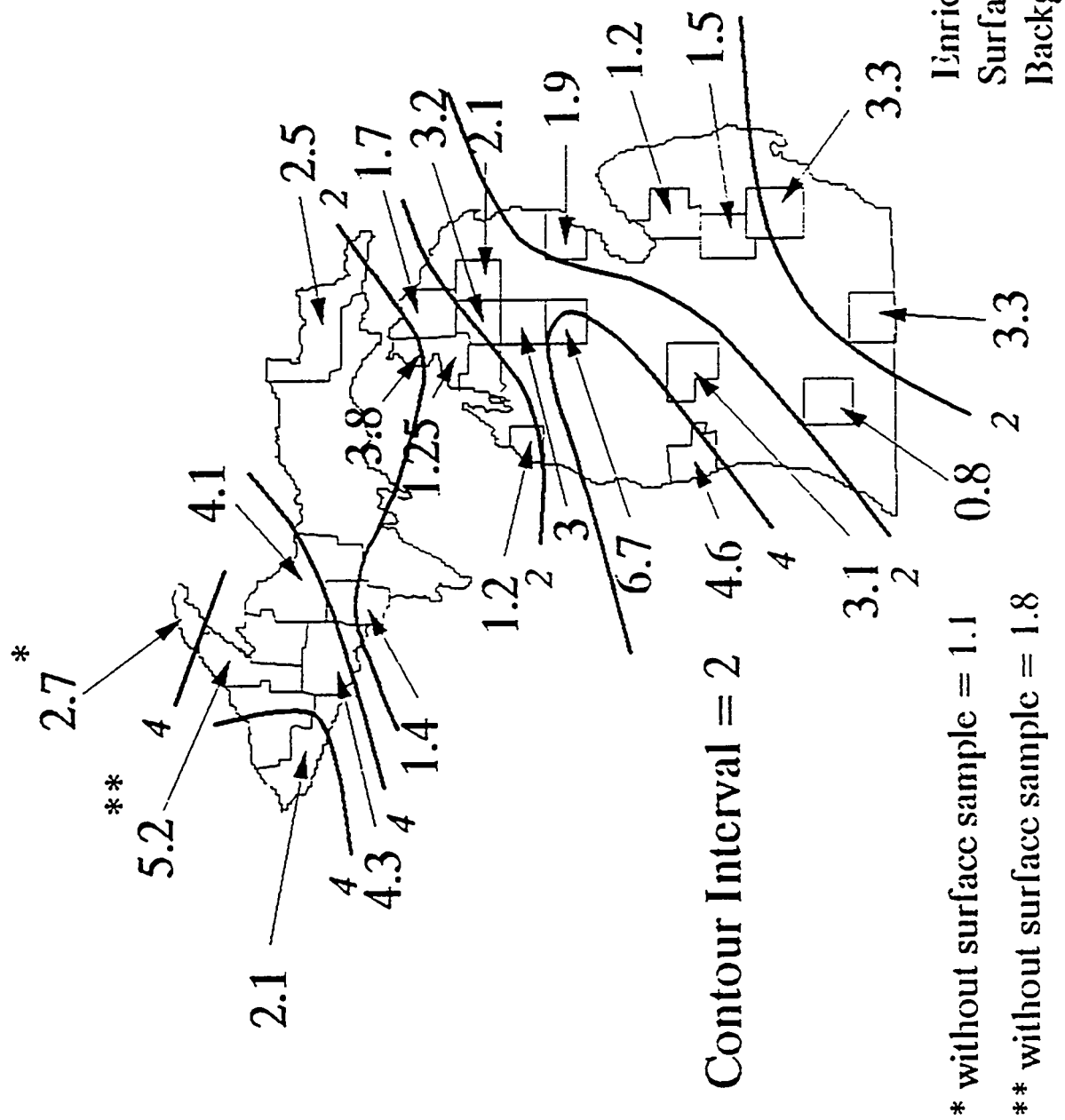
*Contour Interval = 25 ng/g*

Figure 4. Background mercury concentrations (ng/g) in inland lakes; data from Evans, 1993 (from Long, 1993).

Table 4. Background concentrations of arsenic, cadmium, lead and mercury in soils and preliminary background values for sediments of the Great Lakes (from Connor and Shacklette, 1975).

| Parameter                          | Arsenic<br>( $\mu\text{g/g}$ ) | Cadmium<br>( $\mu\text{g/g}$ ) | Lead<br>( $\mu\text{g/g}$ ) | Mercury<br>( $\text{ng/g}$ ) |
|------------------------------------|--------------------------------|--------------------------------|-----------------------------|------------------------------|
| mean <sup>1</sup>                  | 8.53                           | <1.0                           | 19.0                        | 55.0                         |
| range of means <sup>2</sup>        | 5.4-13.0                       | <1.0                           | 2.6-31.0                    | 30.0-160.0                   |
| range of all data <sup>3</sup>     | <0.2-170                       | <1.0-11.0                      | <7.0-700.0                  | <10.0-4,6000                 |
|                                    |                                |                                |                             |                              |
| lake sediments <sup>4</sup>        | 6.23                           | 0.25                           | 13.17                       | 28.82                        |
| range <sup>5</sup>                 | 3.33-11.1                      | 0.12-0.54                      | 4.5-22.84                   | 10.8-36.53                   |
| inland lake sediments <sup>6</sup> | -                              | -                              | -                           | 55.0                         |
| range <sup>7</sup>                 | -                              | -                              | -                           | 18.0-110.0                   |

1. Mean values were calculated for metals concentrations in soils from various areas of the U.S. The mean reported is an average of the means for soil sampling sites.
2. Range of means is the range of the means for metal concentrations in soil sites used to calculate the mean in 1.
3. Range of all data is the range of all data used to calculate the means for metal concentrations in soils from various areas of U.S. The total number of samples analyses for each metal is >1,000.
4. Average background value for various sites in Great Lakes.
5. Range of mean background values for various sites in the Great Lakes.
6. Average background value for various inland lakes in Michigan (from R. Evans, 1993).
7. Range of background values for various inland lakes in Michigan (from R. Evans, 1993).



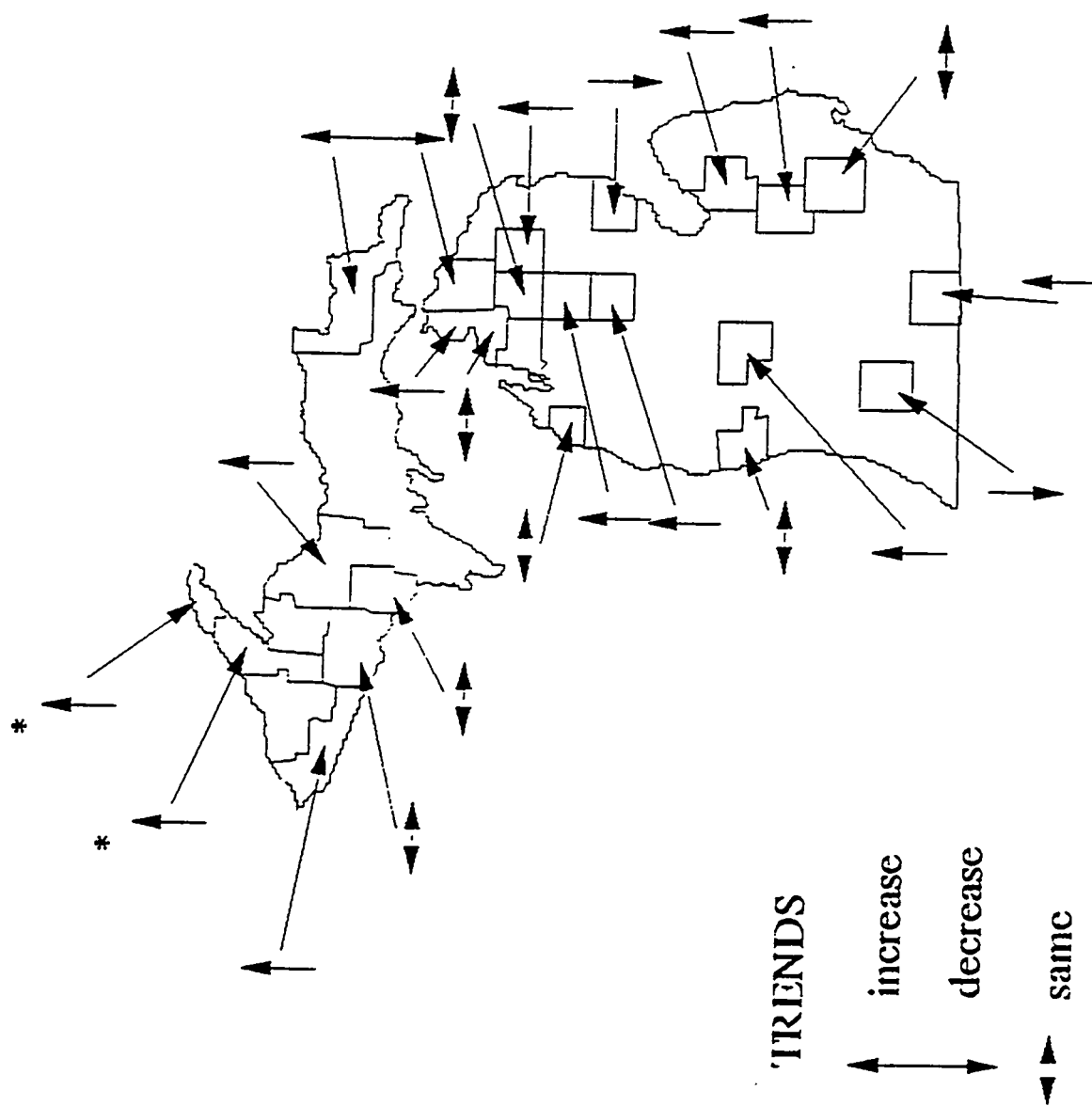


Figure 6. Recent changes in mercury concentrations in inland lakes; data from Evans, 1993 (from: Long, 1993).

are increasing, but it is also possible that the records are incomplete, as in the case of the Great Lakes sediments, or that diagenetic processes have disturbed the record. Thus, the recent trend of mercury loading to Michigan is unclear from the sediment record.

### ***Wildlife Exposure***

The previous discussion demonstrated that mercury can become mobile in sediments. Although the fate of mercury released from sediments is not well known, benthic invertebrates could be exposed to this released mercury. In addition, benthic organisms might release sediment bound mercury by assimilation of the sediment. Mercury can be transferred up the food chain as these organisms are consumed by others.

Because of the documented biological activity of methylmercury, the potential exists for harmful effects in wildlife. These effects would likely be exhibited in species that are near the top of the aquatic food chain because of the bioaccumulation of mercury in the aquatic environment. Fish-eating avian species such as loons, cormorants and eagles may be expected to be susceptible. Although adverse reproductive effects of chemical contamination from point sources in the Great Lakes basin have been documented in fish, cormorants, terns and eagles, there is little evidence that methylmercury is involved at this time in these perturbations.

PCB contamination has been commonly suggested as the cause for deleterious effects in wildlife, especially decreased reproduction and/or developmental problems. Although relatively high mercury levels have been found in samples from loons and eagles in Minnesota, it is uncertain that birds found dead or dying in the wild have been poisoned with methylmercury (Frank et al., 1983). The risks, but not the potential for harm to wildlife from methylmercury contamination in fish, remain unknown at this time. It seems reasonable to believe, however, that actions taken to protect humans from methylmercury effects produced via fish consumption would allow protection of predator wildlife species that consume freshwater fish in their diet. This conclusion is based on the fact that the threshold dose for methylmercury effects in wildlife species as determined from controlled feeding studies appears to be the same or higher than the exposure threshold for adverse effects in humans (MDNR, 1992c). Results from wildlife in the field indicating high levels of methylmercury have not been considered sufficiently reliable to use as indicative of unsafe levels that are present from nonpoint source pollution (Wren, 1991).

### ***Human Exposure***

Humans are exposed to mercury primarily through ingestion of fish that contain mercury (Clement International Corporation, 1992). Inhalation of mercury vapors can create occupational exposure in industries that process or use mercury. Skin contact with

materials containing organic mercury and elemental mercury can also results in mercury exposure. People with dental amalgams that contain mercury may have greater exposure (Summers et al., 1990; Ziff and Ziff, 1992). A comprehensive collection of information related to human exposure of mercury is provided in Appendix III. This document is a draft toxicological profile for mercury prepared by Clement International Corporation (1992) for the U.S. Department of Health and Human Services.

### **Conclusions**

The following conclusions may be drawn regarding the sources and pathways of mercury into the environment and the means by which humans are exposed:

- ◆ Natural emissions of mercury to the environment appear to be significant and may account for on the order of half of the total mercury released into the atmosphere on a global basis. These emissions are derived from microbial-mercury interactions and from release from the earth's crust, due to natural degassing.
- ◆ Approximately half of the input of mercury into the environment is from human sources.
- ◆ The rather uniform concentrations of mercury in Great Lakes sediment cores lends evidence that atmospheric input of mercury is the predominant pathway of entry.
- ◆ Concentrations of mercury are not well known in many environments (e.g., surface water, ground water and urban air).
- ◆ Mercury is being added to the terrestrial as well as aquatic environments, but the terrestrial-aquatic linkages are not well defined.
- ◆ The major sources of anthropogenic mercury are estimated to be waste incineration, coal combustion and latex paint usage. However, of the 3 sources, latex paint is the least of concern due to the recent ban of mercury compounds in the paint.
- ◆ The chemical and physical forms of mercury entering the atmosphere from power plant and incinerator emissions are dependent upon a number of factors and in the absence of source-specific data, it is difficult to model the extent of local or regional contamination from these sources.
- ◆ Humans are exposed to mercury primarily through ingestion of fish that contain mercury and possibly through exposure to dental amalgams.
- ◆ The mercury problem is more than a Michigan problem, it is regional and, perhaps, global in scale. Regional and national

support and cooperation must be obtained to achieve reductions in mercury input to the atmosphere.

**DIRECTIVE #3.** Determine what state, federal and international standards and abatement programs currently exist, and the status of any proposed state and federal regulations.

A compilation of the current and proposed state, federal and international standards and abatement programs was prepared previously by the MDNR (1992c). A brief summary of that material, plus available updates, are presented below.

#### ***Existing Federal Programs***

The federal Insecticide, Fungicide and Rodenticide Act (FIFRA) covers the registration for mercury uses, suspension, cancellation or restriction of pesticides for certain uses and enforcement of the regulatory statute. Mercury compounds had been registered for use as a fungicide in latex paint; however, by 1991 the USEPA had canceled all registrations for the use of mercury compounds in paints and coatings in both interior and exterior paints authorized under the Act. In addition, mercury products previously registered for use in miscellaneous interior products such as spackling and joint compounds, adhesives and acoustical plaster were also canceled.

#### ***Proposed Federal Programs***

***Clean Air Act (CAA).*** Title III of the CAA, as amended, established a list of 189 substances and compounds, including mercury, that must be considered as hazardous air pollutants. The USEPA has to developed a list of the major sources for these substances and is currently working on the development of technology-based emission standards for the identified sources. The standards must require the Maximum Available Control Technology for new and existing sources.

In addition to the above, 4 investigations were called for under the provisions of the CAA. A brief summary and a current status update for the 4 investigations, as provided by MDNR (Taylor, 1993), are presented below:

***Great Waters Study.*** The Great Waters Study [Section 112 (m) of the CAA] requires the USEPA to conduct a program to identify and assess the extent of atmospheric deposition of hazardous air pollutants, including mercury, into the Great Lakes, Chesapeake Bay, Lake Champlain and coastal waters. This study requires an air monitoring network with master research stations located on each of the Great Lakes.

Master stations have been established at the Keweenaw Peninsula, Eagle Harbor for Lake Superior; Sleeping Bear Sand Dunes, Empire for Lake Michigan; Burnt Island off Bruce Peninsula, Canada for



Lake Huron; Point Petre, Canada for Lake Ontario and Sturgeon Point, New York for Lake Erie. Collection of air and precipitation samples of PCBs, PAHs, pesticides and metals (excluding mercury) is currently being conducted. It is not known when mercury sampling will be initiated, but the USEPA has allocated funds to support a regional proposal by Dr. Jerry Keeler, University of Michigan, to establish a mercury air monitoring network in 1994.

Significant effort has taken place on compiling the Great Waters Study report to Congress which will be submitted November 1993 and biennially thereafter. A workshop was held by the USEPA in November 1992 which brought scientific experts together to provide information on focused areas related to atmospheric deposition of toxics to the Great Lakes. Support documents are being developed by scientists for the report to Congress.

Some work is currently being conducted for Section 112 (c) (6) (a related CAA provision) which requires a listing of all source categories which account for at least 90% of the aggregate emissions of 7 pollutants of concern to the Great Lakes including mercury. The USEPA has compiled "locating and estimating" documents to facilitate identification of sources which emit these 7 pollutants of concern. A screening emission inventory is also planned for all 7 pollutants.

**Mercury Study.** The mercury study [Section 112 (n) (1) (B) of the CAA] requires the USEPA to quantify mercury emissions from electric utilities, municipal waste incinerators and other sources, including area sources. Some progress has been made on the mercury study. An initial plan has been developed with the primary goal of developing a national inventory of mercury from all sources, including natural sources. Determination of trends on emissions from sources and consumer goods will also be conducted. The emissions will be modeled using an indirect exposure model to determine both ecological and human health impacts from non-inhalation exposure pathways. A series of reports covering specific topics related to mercury will be developed as the study progresses. Seven areas will be addressed under the mercury study: emissions and source characterization, mercury emission trends, fate and transport, human exposure assessment, human health effects, environmental effects and control technologies and cost. The schedule for the completion of the report is November 1994.

**Utility Study.** The utility study [Section 112 (n) (1) (A) of the CAA] requires the USEPA to study and report on hazardous air pollutants emitted from electric utilities. The USEPA must regulate this source category if appropriate, based on the study results. Funding was cut for the utility study. As a result, no mercury sampling will be conducted. The USEPA will rely on the work from the U.S. Department of Energy and the Electric Power Research Institute (EPRI) studies and plans to use any applicable data from the mercury study to determine mercury emissions from

utilities.

Table 5 presents the mercury research currently underway by EPRI. The utility study is now estimated to be approximately 2 years late and will be submitted in 1995.

Table 5. Mercury research projects currently underway by the Electric Power Research Institute.

|  |  |
|--|--|
| <b>EMISSIONS</b>   |  |
| Speciation (RP 3177-03)  |  |
| Mass Balance (RP 3177-03)                                      |  |
| Methods Intercalibration (DOE)                                 |  |
| Historical Emission Data (RP 2933)                             |  |
| <b>ATMOSPHERIC TRANSPORT/TRANSFORMATION</b>                    |  |
| Process and Reaction Rates (RP 3218-01)                        |  |
| Dry Depositions (RP 3218-02)                                   |  |
| Florida Atmospheric Mercury Study (FAMS) (RP 3297-01)          |  |
| <b>ECOLOGICAL CYCLING/FISH ACCUMULATION</b>                    |  |
| Methods Development (RP 2020-03,04)                            |  |
| Fish and Water Quality (RP 2020-05)                            |  |
| Reservoir and Point Sources (RP 2020-09)                       |  |
| Mercury in Temperate Lakes (MTL) (RP 2020-10)                  |  |
| Historical Depositions (peat cores) (RP 2020-12)               |  |
| Mercury Accumulation Pathways and Processes (MAPP) (RP3297-02) |  |
| Methods Intercalibration (RP 3297-02)                          |  |
| <b>RISK ASSESSMENT/HUMAN HEALTH</b>                            |  |
| Comprehensive Risk Evaluation (CORE) (RP 3081)                 |  |
| Risk--PISCES (RP 3081)   |  |
| Human Health Assessment (RP 2310)                              |  |

Source: Porcella (1992).

**National Institute of Environmental Health Sciences (NIEHS) Study.** The NIEHS study [Section 112 (n) (1) (c) of the CAA] requires NIEHS to conduct a study to determine the threshold level of mercury exposure below which adverse human health effects are not expected to occur. Additionally, this study must include a threshold for mercury concentrations in the tissue of fish which may be consumed, including consumption by sensitive populations, without adverse effects to public health.

According to Taylor (1993), the NIEHS study has been completed and was submitted to the director of NIEHS in January 1993. No action has been taken on approval and official release of the report. Once released, the study should be carefully evaluated by the state.

### **Other Federal Programs**

**Agency for Toxic Substances and Disease Registry (ATSDR).** The ATSDR of the U.S. Public Health Service has proposed an order of magnitude reduction in the standard for the ADI of methylmercury from the present USEPA limit of 0.3 µg/kg/day to a reduced ADI of 0.04 µg/kg/day. The USEPA is expected to withdraw the 0.3 µg/kg/day standard for reevaluation. If the ADI decreases by nearly 1 order of magnitude, the risks posed by consumption of fish in Michigan may require a ban on the eating of these fish by certain elements of the population. The state will need to track this development very closely.

**The Clean Water Act (CWA).** The CWA proposed reauthorization includes a ban on the discharge of several pollutants, including mercury. It is anticipated that action on the reauthorization of the CWA will take place sometime during 1993.

**The Great Lakes Water Quality Initiative (GLWQI).** The GLWQI is required by the Great Lakes Critical Programs Act of 1990. The GLWQI will establish water quality standards for the Great Lakes basin. On March 31, 1993, the USEPA announced the release of its proposed quality guidance for the Great Lakes ecosystem (USEPA, 1993a). The guidance will require the 8 Great Lakes states and certain Indian tribes to establish consistent, scientifically-based controls on toxic pollutants in the Great Lakes basin.

According to the USEPA, the guidance will result in consistent, basin-wide water quality standards designed to protect human health, aquatic life and wildlife. The guidance proposes human health criteria for 20 pollutants, aquatic life criteria for 16 pollutants and wildlife criteria for 4 pollutants. The guidance contains methodologies for developing additional criteria and values for the protection of human health, aquatic life and wildlife. The guidance also includes proposed detailed provisions on antidegradation and detailed requirements for establishing or implementing important elements of National Pollutant Discharge Elimination System (NPDES) permits and water quality programs.

The proposed guidance is to be published in the Federal Register followed by a 150-day written public comment period. The USEPA will also hold a public hearing in August 1993 at its regional office in Chicago, Illinois. Once the final language is published, the Great Lakes states will have 2 years to adopt water quality standards consistent with those contained in the guidance.

### **Proposed Federal Legislation**

On October 3, 1991, Michigan Congressman Howard Wolpe sponsored a bill (H.R. 3509) entitled, "The Solid Waste Metals Reduction Act", on behalf of the Northeast-Midwest Congressional Coalition. The purpose of the bill was to eliminate the use of 4 heavy metals

(mercury, lead, cadmium and chromium) in packaging and packaging materials. The only exemption from the bill's prohibition would include packaging for x-rays and similar medical applications. Ten states currently have such prohibitions in their laws. According to Congressman Wolpe's office, the bill is currently inactive and probably will not be acted upon.

### ***Existing State Programs***

The Michigan Pesticide Control Act of 1976 and FIFRA grant the Michigan Department of Agriculture (MDA) the authority to regulate all pesticides sold in Michigan. Currently there are 7 pesticide products registered for sale in Michigan which contain a mercurial in their formulation. All allegations of product misuse are investigated by MDA inspectors.

The MDPH issues, on an annual basis, fish consumption advisories. The purpose of the advisories is to advise the public as to the risk of eating Michigan sport-caught fish that have been found to contain various contaminants, including mercury. The advisories are developed primarily by using fish tissue contaminant data generated by the MDNR's fish contaminants monitoring program. Due to widespread contamination, the MDPH has issued a generic advisory recommending limited consumption of select species from all of Michigan's inland lakes.

Michigan regulates surface water quality and surface water dischargers under the Water Resources Commission Act (Public Act 245 of 1929, as amended) and the NPDES, respectively. Part 4 of the General Rules of the Water Resources Commission establishes Michigan's Water Quality Standards (MWQS). The standards most relevant to mercury are Rules 57 and 99. Under the MWQS, the standard for total mercury in Michigan surface waters is set at 1.3 ng/l. Michigan surface water discharge permit levels for mercury are set to ensure that receiving waters do not exceed this standard. Until recently, however, the technology and methods have not been available to accurately measure mercury in water below 0.2 µg/l (or 200 ng/l). Therefore, all permittees are currently allowed discharge of total mercury as long as it is below 0.2 µg/l (over 150 times the level mandated by the MWQS).

There remains some question as to whether the MWQS correctly identifies a standard for total mercury or methylmercury. Jones (1992) describes calculations of the MWQS that assume an acceptable daily intake of 4 µg/day methylmercury, an average daily consumption of contaminated fish at 6.5 g/day and a methylmercury bioconcentration factor of 500,000. He concludes that the resultant allowable water body concentration should be correctly recognized as 1.3 ng/l methylmercury. This distinction does not affect MDNR identification of surface waters that may be violating the MWQS (based on high fish concentrations) but it does become important when limits are set by which industrial effluents must

abide. Site specific measurements must be made that identify and distinguish between methylmercury and total mercury (in the same way that the distinction between total chromium and hexavalent chromium is made).

The MDNR currently maintains a Fish Contaminant Monitoring Program (FCMP) to quantitatively assess the degree of chemical contamination in fish from waters throughout the state (MDNR, 1992b; MDNR, 1991). The program monitors the level of mercury and several organic chemicals in fish tissue. The FCMP includes a trend monitoring effort which was initiated in 1990 to better identify changes in fish contaminant levels. This effort consists of periodic fish sampling (once every 2 to 5 years) of select species from 27 locations representing inland lakes, rivers, the Great Lakes and connecting channels.

Under Michigan's Air Pollution Control Act (Public Act 348 of 1965, as amended), limits for mercury emitted from air sources are established on a case by case basis. Emission limits for mercury will vary depending on several variables including applicable regulations, source type, control equipment, stack height and capacity. Relatively new air toxic rules, effective April 1992, require that all sources evaluate emissions of toxic pollutants, including mercury, and that Best Available Control Technology be used to eliminate or minimize toxic materials.

On December 18, 1992, Public Act 283 was signed into law creating a deposit system for lead acid, nickel cadmium and mercury batteries. According to the new law, an individual who purchases a new battery may either exchange a used battery or pay a deposit (\$6.00 for lead acid batteries, \$2.00 for nickel cadmium or mercury batteries). Upon return of the battery to either the retailer who sold the battery or to a MDNR-approved collection facility, the purchaser may obtain a refund of the deposit. The lead acid battery program will become effective July 1, 1995 and the nickel cadmium and mercury battery programs will become effective January 1, 1998.

### ***Proposed State Legislation***

Two bill requests dealing with batteries have been drafted. The first bill request is designed to amend Section 30a of the Solid Waste Management Act (Public Act 641 of 1978, as amended) by prohibiting disposal into either a solid waste landfill or incinerator of lead acid, nickel cadmium, mercury, lithium or silver oxide batteries. In addition, the bill request would require that solid waste management plans contain provisions for: (1) the removal from the waste stream of alkaline and carbon zinc batteries and (2) the incorporation of Household Hazardous Wastes Collection Programs which would include the collection of alkaline and carbon zinc batteries.

The second bill request would amend Sections 1 and 3 of the Battery Disposal Act (Public Act 20 of 1990) by requiring that all battery operated products be designed so as to allow the battery to be removed from the product or be contained in a separate removable battery pack. The bill request would require that all alkaline and carbon zinc batteries not be sold in the state if the mercury content is greater than 0.025% by weight and that a 2 cent (per gram of nickel and/or cadmium content of the battery) surcharge be made on any person who resales a nickel cadmium battery (a minimum surcharge of 10 cents will be imposed per battery). The bill request would also prohibit the sale of mercury, lithium and silver oxide batteries in the state except for scientific, technical or medical purposes. A study is also called for in the bill request which would evaluate the environmental impact of nickel hydride batteries. It is not known at this time if either of the two bill requests will be introduced.

### ***Regional Programs***

On May 21, 1986, the Governors of the 8 Great Lakes states adopted the Great Lakes Toxics Substance Control Agreement. The purpose of the agreement was to establish a framework for coordinating regional action in controlling toxic pollutants entering the Great Lakes systems; to further understand toxic contaminants and ways to control them; and to redirect the states' common goals, management practices and control strategies for integrated protection of the Great Lakes ecosystem. On September 8, 1986, the environmental administrators of the same states signed an agreement which included specific commitments towards coordinated regional management of discharges, releases or emissions of toxic substances in the Great Lakes basin. The Great Lakes Toxic Substance Control Agreement also mandated that a uniform fish consumption advisory protocol be developed for the Great Lakes basin. A Great Lakes Fish Consumption Advisory Task Force was established in 1986 to develop this protocol. Work is continuing on this effort.

On November 3, 1988, representatives of the Council of Great Lakes Governors entered into the Great Lakes Air Permitting Agreement. This agreement addresses the control of emissions of 7 toxic chemicals, including mercury, in the Great Lakes basin to minimize the impact of toxics on the Great Lakes. Each of the Great Lakes states' air permitting groups must review all air permit applications for the emissions of the 7 compounds and Best Available Control Technology must be required. Implementation began in 1990.

Funding for the development of a regional air toxic computerized emission inventory was received in 1991 from the Regional Great Lakes Protection Fund. The project, when finalized, will consist of a regional computer inventory of 25 air toxics, including mercury, emitted from point, area and mobile sources for all Great Lakes states. A preliminary data base is expected to be completed

in 1993.

### ***International Programs***

In 1978, the U.S. and Canada signed the Great Lakes Water Quality Agreement "to restore and maintain chemical, physical, and biological integrity of the Great Lakes Basin and Ecosystem". The agreement outlines specific objectives for persistent toxic substances as well as outlining programs and other measures to fulfill the purposes of the agreement. The specific concentration objectives for mercury outlined in the agreement are 0.2 µg/l in surface waters and 0.5 mg/kg in whole fish to protect aquatic life and fish-consuming birds.

The programs addressed by the agreement include Remedial Action Plans (RAPs) for the Great Lakes Areas of Concern (AOC), Lakewide Management Plans (LaMP) and airborne toxics. AOC are sites in the Great Lakes basin which have been identified as being contaminated. The RAPs also outline clean up strategies and preventative measures for each of the AOCs in the Great Lakes basin. There are 14 AOCs within Michigan, with 6 having use impairments due to mercury.

LaMPs must be developed for each of the 5 Great Lakes, as outlined in Annex 2 of the Great Lakes Water Quality Agreement. State and Canadian provincial governments are required to work together on all LaMPs, with the exception of the Lake Michigan LaMP, which is the sole responsibility of the U.S. LaMPs must be designed to reduce loadings of critical pollutants in order to restore beneficial uses. The LaMPs must also preserve pristine areas by developing preventative measures. A draft of the Lake Michigan LaMP has been developed by the surrounding states and the USEPA, and mercury has been included as a critical pollutant.

Annex 15 of the Great Lakes Water Quality Agreement, titled "Airborne Toxic Substances", outlines activities that Canada and the U.S. will carry out to reduce atmospheric deposition of toxic substances to the Great Lakes basin ecosystem. Such activities include research, monitoring and pollution control measures. Research efforts include requirements to understand the processes of wet and dry deposition and the risks from indirect exposure of toxic substances as well as the development of intermediate and long range models to track the source and significance of loadings to the basin. Monitoring efforts require that an Integrated Atmospheric Deposition Network (IADN) be established to determine atmospheric loadings to the basin. This IADN network is being modified to coincide with the requirements of the CAA.

In the IJC's fifth biennial report on the Great Lakes Water Quality Agreement (IJC, 1990), the IJC recommended that "the parties designate Lake Superior as a demonstration area where no point source discharge of any persistent toxic chemical will be permitted". This recommendation led to the bi-national program to

restore and protect the Lake Superior basin to pursue the goal of zero discharge announced by the USEPA in April 1991. The LaMP process will be used to implement the zero discharge strategy utilizing the CWA and CAA as tools for successful implementation.

### ***Other Programs***

The state of New Jersey recently completed a draft of a comprehensive investigation designed to develop and set emission standards for mercury (NJDEPE, 1992). In the draft study, several anthropogenic sources for mercury emissions were identified; including, municipal solid waste incineration, fuel oil combustion, coal burning utilities, municipal sludge incineration, natural gas and gasoline, crematories, and industrial sources other than fuel combustion. The study recommended source reduction, especially mercury in batteries and certain electrical components and packaging materials, to help reduce the level of mercury coming from the human sources. The draft New Jersey study adopted as an emission standard for municipal solid waste incinerators of 28 µg/dscm at 7% oxygen to be reached by the year 2000 through a combination of control technologies and source reduction. The study asserts that this is the most stringent mercury limitation in the world and one which can be achieved. The New Jersey study also recommended an ADI of 0.07 mg/kg/day for methylmercury. It should be noted that this draft New Jersey study has been severely criticized (Jarabek, 1993; Jones, 1993; Burton, 1992; Ferraro, 1992). The comment period for the draft study has expired. The state should keep itself apprised of the outcome of this effort.

The State of Minnesota recently completed a report on the management of mercury-containing lamps (fluorescent and high-intensity discharge lamps) (Moore, 1993). It should be noted that after mercury in batteries, mercury in lamps constitutes the major source of mercury in municipal solid waste. Accordingly, the key findings and key recommendations of this study should be reviewed carefully for possible implementation in Michigan. In particular, the recommendations of Minnesota regarding source reduction of mercury in the lamps, the separate collection and management proposal and recycling need to be evaluated for potential application in Michigan.

### ***Conclusions***

♦ Recent federal and state legislative initiatives and regulatory programs (e.g., cancellation of mercury compounds in latex paints, phasing out of chloralkali plants, implementation of battery recycling programs, etc.) are anticipated to be successful in helping to reduce the input of anthropogenic sources of mercury into the Great Lakes environment.

♦ Recent agreements among the Great Lakes states (e.g., Great Lakes Toxics Substance Control Agreement, Great Lakes Air Permitting



Agreement) and the older U.S. - Canada Great Lakes Water Quality Agreement deal with a variety of water and air environmental contamination regulatory and programmatic concerns. Together, these agreements constitute a beginning of a focused and concerted effort to help control and reduce the input of mercury (and other pollutants) into the Great Lakes region.

♦ There are many ongoing and/or planned state, federal, regional and international research initiatives, and several state and federal legislative initiatives which, if carried through, should help to further reduce, control and/or regulate the input of anthropogenic mercury into the Great Lakes region.

♦ The ongoing and planned state, federal, regional and international research programs and initiatives are dynamic in nature and will address a variety of separate but interrelated mercury concerns and questions. In order for Michigan to objectively evaluate the results of these investigations and their possible impact on existing programs and proposed legislation, there will be a need for the state to keep abreast of the results and conclusions of these studies. Currently, Michigan does not maintain central repository for this type of material. As a consequence, Michigan does not maintain a comprehensive, up-to-date research data base on mercury.

**DIRECTIVE #4. Propose and evaluate options for controlling or eliminating harmful emissions of mercury into the environment.**

***General***

A knowledge of the unknowns and uncertainties presented in Directive #2 of this report is a prerequisite to assessing the desirability and impact of the various mercury emission control options. For example, if gaseous mercury-zero emissions predominate in mercury deposition, then scrubbers that reduce particulate mercury-two and gaseous mercury-two or particulate control devices that reduce particulate mercury-two may not be necessary. If, on the other hand, particulate mercury-two is the determining species, then control of gaseous mercury-zero may not be necessary. Consequently, some of the questions raised in Directive #2 must be answered in order to develop a control strategy that will reduce mercury deposition.

While it is not known how much of the mercury comes from outside the state, it is clear that substantial reductions in mercury release to the environment will not occur if Michigan acts on the problem alone. Efforts are needed on a regional, national and, probably, global basis. Some of these efforts are already underway, presenting Michigan opportunities to participate in the decision-making process. Nevertheless, the purpose of this section is to examine the control options available to Michigan.

It is not known precisely how much Michigan citizens need to reduce their use of mercury-containing products in their businesses and homes in order to reduce mercury levels in the fish from Michigan's inland lakes, or even if such reductions will have any impact on mercury levels in the fish. But some of the sources of mercury emissions into the environment are known and there is some general understanding of potential options on how to reduce those emissions.

On a global basis, about 50% of the total mercury emissions is thought to be natural. If this percentage applies to the observed ambient air concentrations in Michigan and if deposition is proportional to total emissions, then the mercury in the fish in Michigan's lakes cannot be reduced by more than 50% by eliminating all anthropogenic sources within the state. It is highly unlikely that all of the observed mercury of human origin in the state comes solely from Michigan, so even complete elimination of mercury emissions within the state would reduce current atmospheric levels of total mercury by less than half.

According to the MDNR's (1992c) estimated emission inventory, about three-quarters of the anthropogenic mercury emissions come from latex paint usage, coal-fired power plants and solid waste

incineration. The remaining sources of mercury emissions are diffuse and include emissions from broken fluorescent lamps, instruments, laboratories and industrial processes. It is unknown what percentage of emissions are in the particulate mercury-two and gaseous mercury-two forms that are likely to be involved in most of the local deposition of mercury-two in the state.

**Latex Paint Emissions.** If latex paint did not contain mercury, total mercury emissions might be reduced as much as 25%, though, for technical reasons given previously, reduction in wet deposition of mercury may be substantially less than this. However, the USEPA banned mercury compounds in interior paints in 1990 and exterior paints in 1991, so mercury emissions from this source will decrease substantially. The amount of remaining stocks is unknown, but the USEPA estimates that mercury from discarded paint in municipal solid waste across the nation should decrease from 17.5 short tons in 1990 to 2.3 short tons by 1995 and 0.5 short tons by 2000. This suggests that mercury emissions from latex paint containing mercury additives should decline relatively rapidly.

**Waste Combustion.** There is disagreement over whether municipal waste will become a larger or smaller source of potential mercury emissions over the next few years (KBN Engineering and Applied Sciences, 1992; Volland, 1991; USEPA, 1992; Shieh, 1992; Balfour, 1992). Some have reasoned that reduced use of mercury in paints and electrical cells and switches, as well as special collection programs, will result in reduced emissions. Others counter that the increased use of waste combustion, the ineffectiveness of battery collection programs, and the overestimation of the contribution of batteries and cells to overall mercury content in the waste stream will ensure that municipal waste combustion will not change or even grow as a source for mercury emissions. There is currently too little information available to lead to a reliable conclusion regarding which of these postulates is correct. In either case, there is sufficient reason, given the potential health hazard, to specify mercury emission limits. Upon enacting the 1990 amendments to the CAA, Congress has mandated that the USEPA set limits for mercury from such combustors and indeed, several states and foreign countries have already set or are considering setting limits on mercury emissions.

Although methods of determining even an average estimate of the amount of mercury in a heterogeneous and changing municipal waste stream are fraught with difficulty; mixed municipal waste is known to contain significant levels of mercury-containing components (KBN Engineering and Applied Sciences, 1992; NJDEPE, 1992; MDNR, 1992c; USEPA, 1992). The quantities of mercury emitted in the flue gases varies widely not only from facility to facility but also over time for a given installation. Emissions are a function of the amount of mercury contained in the incoming waste, the incinerator design and operating conditions, and of the efficiency of gas cleaning devices. Add to this the uncertainties associated with stack

sampling and trace analysis, it is understandable why it is difficult to obtain accurate emission levels from those few studies which have been done.

Recent work has shown that most of the mercury emitted from municipal waste incinerators is primarily present as mercury-two chloride rather than as elemental mercury (Rothstein et al., 1991). The mercuric chloride is formed in the stack when the gaseous mercury-zero reacts with chlorine which is liberated when plastic materials in the waste are combusted.

Studies show that gas cleaning technologies in addition to those generally required and used can substantially reduce mercury levels in emissions from municipal waste combustors (NJDEPE, 1992; White et al., 1992; Nebel et al., 1992). Activated carbon injection, sulfide injection and wet scrubbing systems all are reported effective. In Europe, wet scrubbing has tended to be the method or choice to control mercury (along with certain other pollutants), while carbon injection tends to be favored by vendors and operators in the U.S. (presumably because of its compatibility with and ease of retrofit onto spray-dryer/baghouse systems).

Total mercury emissions from medical waste incinerators have been estimated to be approximately one-quarter those from municipal waste combustors. Medical waste is known to contain significant sources of mercury (KBN Engineering and Applied Sciences, 1992; NJDEPE, 1992; Volland, 1992), but the amount of waste burned in these more numerous but smaller units is considerably less. However, most are fitted with less sophisticated pollution control equipment and may represent significant sources of water-soluble mercury-two.

Combustion of wastes classified as hazardous presents another possible source of mercury emissions to the atmosphere, particularly in conjunction with industrial boilers, furnaces and kilns not fitted with wet scrubbers. Hazardous wastes are generally more homogeneous and easier to characterize than the mixed municipal waste stream. Nonetheless, there are many cases of complex and incompletely characterized mixtures, particularly those coming from a number of disparate sources and ending up in commercial hazardous waste incinerator facilities. Although regulatory agencies attempt to anticipate potential problems and prevent them by setting a variety of limits on what can be burned and at what maximum levels, experience has shown that this is not always successful. This applies not only to anticipation of all potential problems of content but also to monitoring and enforcement of limits. For example, it has been reported that a single waste shipment to a Michigan-based cement kiln/hazardous waste operation contained over a ton of mercury (Taylor, 1992). This facility currently has no emission limit for mercury specified in its permit for air emissions, illustrating the potential significance of this waste sector within Michigan.

In the short-run, it is likely that mercury will continue to be present in many consumer products, so requiring the best available control technologies on incinerators to reduce mercury emissions needs to be a priority. Carbon injection systems on scrubbers may control up to 90% mercury emissions from incinerators. There is still considerable uncertainty about what the cost of installing this technology would be. This technology may increase costs of municipal solid waste disposal roughly \$1.00 or more per ton of waste disposed depending on the type of incinerator. The cost of installing controls on medical waste incinerators may be higher and may be approximately \$6.00 per ton of waste disposed (White and Jackson, 1992).

There are a number of waste combustion practices which, either individually or collectively, have not been considered to be major sources of mercury in air (NJDEPE, 1992). These include open burning of construction debris and vegetative matter, sludge incinerators, crematoria, and small incinerators for schools, apartment buildings and stores. Studies and inventories are not complete, although it seems unlikely that further data will change their relative importance significantly, at least until other major sources are reduced. The USEPA will soon set limits for mercury levels in sludge for land application and combustion (USEPA, 1993b).

**Waste Separation and Recycling.** Presently, recycling of mercury from new scrap produced during industrial processes is quite extensive. About half of mercury supplies in the U.S. come from recycled sources (Tietenberg, 1992). However, recycling of mercury is not economical for most consumer products because mercury is present in tiny amounts (LSB, 1992; USEPA, 1992). One exception is mercuric oxide "button" batteries commonly used in hearing aids, medical devices and pagers (Ammerman and Van Maele, 1990; Van Maele, 1990). These batteries contain sufficient mercury that at least 3 companies in the U.S. currently recover mercury from them. For example, the Mercury Refining Company in Albany, New York currently charges \$1.50 a pound for accepting mercuric oxide batteries for recycling (Wiley, 1992). The company also sells collection boxes and has informational materials for establishing battery collection programs.

It is possible to reduce some mercury emissions through actions taken with regard to other elements found in batteries. For example, some household batteries such as silver oxide and nickel cadmium contain too little mercury to be economically recycled, but contain other elements that are potentially recyclable. Still other batteries, such as alkaline and carbon zinc, contain hazardous substances that cannot be recycled and are more properly handled at hazardous waste facilities.

A feasible solution for reducing mercury in municipal solid waste coming from products containing non-recyclable amounts of mercury

is the development of safer substitutes for mercury or switching to products that can be economically recycled. There is ample evidence that the development of mercury substitutes occurs when the cost of using mercury increases (USEPA, 1992). For example, in anticipation of controls on mercury use, the latex paint industry found substitutes for the fungicidal properties of mercury in paint. The battery industry has significantly reduced the amount of mercury in alkaline batteries because of pressure to reduce mercury and other heavy metal in municipal solid waste, and it intends to eliminate all mercury in these alkaline batteries in the near future. The mercury content in fluorescent and high intensity lamps has been reduced over the past 5 years. The use of mercury in pigments has been declining steadily. Fever thermometers containing mercury are being replaced by digital thermometers. As a result of these declines, the mercury content of municipal waste is predicted to decline by 76% between the years 1989 and 2000. However, despite these reductions of mercury in products, more fluorescent lamps are expected to be in use by the year 2000, so the total amount of mercury from lamps in municipal waste may continue to increase. This outcome suggests a need for a national and global effort to create additional incentives to develop safer substitutes for mercury and/or to encourage the production of products which can be economically recycled.

**Combustion of Fossil Fuels.** Combustion of fossil fuels, particularly coal, is thought to be a significant, perhaps the largest, source of airborne mercury (KBN Engineering and Applied Sciences, 1992; NJDEPE, 1992; MDNR, 1992c). However, there is considerable range in the estimates available and controversy exists among proponents of waste incineration, the utilities industry and others (Neme, 1991; Leonard, 1992; Widenman, 1992; Ferraro, 1992). Much of this controversy results from the wide range of mercury concentrations in coal, assumptions about how much mercury is retained in the ash or removed by emission control systems and the selective use of high or low bounds of particular studies. However, it is likely that coal-burning utilities will be deemed a significant source of environmental mercury nationwide when all the data are in. Michigan may be in a better position than other areas because of the use of low-sulfur, low-mercury coal by its utilities, but estimates do vary widely (MDNR, 1992c; Widenman, 1992). This will only be settled in final fashion when results of ongoing studies are made available.

Control of mercury emissions from coal-fired utilities is potentially more challenging and costly than from municipal waste combustors. At the present time, use of low-mercury coal is the most effective control of mercury output. Electrostatic precipitators and dry scrubbing have only a moderate effect upon mercury control. Wet scrubbing is more effective at mercury removal from the gas stream but creates contaminated scrubbing water which must be treated. However, instead of installing scrubbers to reduce sulfur dioxide emissions, Michigan's electric

utilities chose to use low sulfur coal. Michigan will need to keep careful watch on the progress of studies currently underway on coal, natural gas, fuel oil and other fossil fuels.

### ***Proposed Options For Controlling Mercury Emissions***

**Recommendation #1.** A standard requiring the installation of state-of-the-art control technology should be set for all facilities. Municipal waste combustion represents a significant source of airborne mercury in Michigan's environment. Improved removal of mercury from flue gases of modern municipal waste incinerators is both technically and economically feasible (NJDEPE, 1992; White et al., 1992; Nebel et al., 1992). Michigan should adopt strict mercury emission standards for all existing and proposed municipal waste incinerators and ensure that it is monitored and enforced. For existing sources, the USEPA is required by the CAA to identify the Maximum Available Control Technology and establish compliance dates. Implementation of these recommendations would likely result in installation of activated carbon injection in municipal waste combustors and carbon injection with dry sorbent injection/baghouse in medical waste incinerators. These technologies would suffice as an interim measure until diversion of mercury from the waste stream is further accomplished, but they do not assure the permanent isolation of mercury from the environment due to the mercury-enriched residues they produce.

**Recommendation #2.** Although additional pollution control equipment will be needed as a result of following Recommendation #1 in the short term, some combination of serious voluntary and mandatory source reduction, separation and collection programs with appropriate incentives and penalties may be the most satisfactory responses to the problems associated with mercury and other components of the solid waste stream. Even highly effective air pollution control equipment only succeeds in moving mercury from one environmental medium to another. There is little assurance that mercury and other hazardous components deposited in landfills will remain out of the general environment permanently. Mercury and other problematic heavy metals last forever; constructs of human engineering do not. All evidence of immobilization of mercury and other metals in landfills addresses only the retardation of metals reaching groundwater, soils and/or air. Re-entry of mercury into the environment is really a question of at what rate and with what effect with current landfill and immobilization practices (Lee and Jones, 1992; Forrester and Goodwin, 1989). Thus, with appropriate incentives and penalties, Michigan should follow the lead of others in making reduction of mercury at the source and collection/recycling programs an immediate and integral part of reducing mercury emissions from incinerators. For example, reduction of mercury use in packaging, electric cells, switches, lamps and other sources, as well as mandatory collection strategies are already a part of Minnesota and New Jersey programs. Michigan should work with other states and

the federal government to elicit their cooperation with strict emission limits and source reduction since mercury and other pollutants respect no boundaries. Efforts of public education and voluntary actions are necessary but, alone, are insufficient strategies to solve mercury and other problems associated with waste disposal.

**Recommendation #3.** The state of Michigan should consider designing a self-financing collection and recycling program for mercuric oxide batteries which establishes effective and fair incentives to recycle. The costs of establishing collection points and paying shipping and recycling charges could be defrayed by placing a deposit or tax on the batteries. Because a deposit or tax would not create an effective incentive to recycle if batteries could be purchased more economically elsewhere, the design of the program must consider also economic incentives. For instance, tax incentives might be considered for Michigan industries, businesses and municipalities which implement safer and/or recyclable alternatives to the use of mercury in products in the state. Similarly, a tax incentive could also be considered for establishment of industries and processes that recycle or permanently immobilize mercury.

**Recommendation #4.** Michigan and the federal government need to be much more serious about waste reduction, detoxification and reuse. This is consistent with state and federal objectives but sufficient funding, incentives and laws and regulation have been lacking. Regulations and technology continue to change regularly as more is learned about the complexities of conversion and containment of problem substances from incineration. Mercury is but the most recent of several concerns in connection with incineration of the mixed solid waste stream. The IJC (1992) has called for a serious re-examination of the current pollution control approach to waste management.

**Recommendation #5.** Any remaining uncontrolled sources of solid waste combustion (e.g., apartment, school and store incinerators) should continue to be phased out and hospital incinerators should be brought under stricter regulation for mercury and other emissions. Florida and Tennessee have enacted a moratorium on permits for new medical waste incinerators. If studies document that these sources are, in fact, important contributors to mercury deposition in Michigan, the state may want to consider this option until such time as adequate control technologies become available.

**Recommendation #6.** Facilities which incinerate hazardous waste should be required to include mercury in their incineration monitoring since there are significant amounts of mercury potentially available (either knowingly or unknowingly) for input into combustion devices. Particular attention should be paid to industrial boilers, furnaces and cement kilns which accept hazardous wastes. These facilities have little capability of



capturing mercury in the off-gases because they are generally not fitted with wet scrubbing devices. Mercury input and emissions limits should be set as a permit condition for all existing and proposed facilities which receive hazardous waste. This is consistent with actions that are anticipated due the 1990 CAA amendments.

**Recommendation #7.** It is recommended that the Michigan Public Service Commission (PSC) be directed to require utilities to perform testing on their facilities to determine the amounts and the forms of mercury in their emissions so that they are in a position to determine which emission control technologies are most appropriate for their specific facilities and in a position to accurately assess their contribution to the total mercury emission inventory. Because it is not possible to characterize the best available technologies for controlling mercury emissions from coal-fired power plants at this time, a prudent strategy for the state would be to require its utilities to develop the information needed to make future permitting decisions. In particular, source samples to measure the concentrations of the various mercury forms are needed to ensure development of truly effective control technologies. While research to develop the technologies is currently being conducted by EPRI and the USEPA, Michigan has need of timely data relevant to the possibly unique conditions existing within the state. These data requirements could be instituted as part of the PSC's regular process of reviewing long range generating capacity plans, and the costs of the research could be recovered through modest increases in utility rates. The PSC should also be directed to monitor the results of the EPRI and USEPA studies, as well as any other relevant studies, to develop a characterization of the control technologies consistent with the requirements of the CAA. Finally, the current practice of coal washing should be jointly evaluated by the power companies and the PSC with the ultimate goal being the development of the most appropriate criteria to be followed.

**Recommendation #8.** All facilities that are potential significant sources of airborne mercury should be required to perform speciated source testing so that a more realistic emissions inventory can be developed. Optimum and cost effective control strategies can only be developed based on reliable emissions information.

**DIRECTIVE #5. Recommend what further studies may be needed in order to implement the above charges.**

This report has raised a variety of questions which will need to be resolved before the state can proceed with a comprehensive program to mitigate the impact of mercury in its environment. The following recommended studies and/or evaluations will help to answer the questions and concerns raised in this report.

***Water Quality and Biological Monitoring Needs***

♦ ***Michigan's Fish Contaminant Monitoring Program should be supplemented with surface water and sediment sampling data in order to develop a sound information base in terms of background and changes in mercury levels.*** There currently is not enough evidence to conclude that mercury levels in fish are increasing over time (Kelly et al., 1975; Schmitt and Brambaugh, 1990; MDNR, 1992b). Such a data base will allow for more accurate evaluations of the impact of mercury reduction measures.

♦ ***Michigan's earlier research (MDNR 1992a) on mercury levels in bald eagle feathers should be repeated periodically; possibly once every 5 years.*** The first study found elevated levels of mercury in adult and eaglet feathers in the Great Lakes region (mean mercury concentration in adult birds and eaglets was found to be 21.9 mg/kg and 9.3 mg/kg, respectively). These data would be useful in helping to determine the impact of mercury in the state's more remote areas as well as providing additional trend information.

♦ ***Michigan needs to begin establishing a new mercury data base on surface water quality using the new sampling techniques. In addition, the state needs to require that current and new Michigan permitted surface water dischargers also use the same protocol.*** Technology and methods are now available to measure surface water total mercury and methylmercury below the limits established by the Michigan Water Quality Standards (MWQS) (Brigham and Brezonik, 1992; Fitzgerald and Watras, 1989). The availability of this capability has not only all but nullified previously collected water quality data, it has also placed into suspect current interpretations of the MWQS standard for mercury. With the additional information will come the capability to better evaluate the impact of mercury on the state's water bodies.

♦ ***Previously collected Michigan data (Evans et al., 1991) on heavy metals in lake sediments need to be reevaluated using math-based receptor modeling techniques in order to provide information on the sources of mercury in the sediments.***

## ***Emissions and Air Quality Data Needs***

♦ ***Michigan should conduct measurements (air and deposition) in and around Detroit to determine the sources and the geographic extent of high mercury concentrations.*** Measurements made in Detroit indicated high presence of some strong local sources of mercury emissions (concentrations of elemental mercury and particulate mercury were as high as 70 ng/m<sup>3</sup> and 1,230 pg/m<sup>3</sup>, respectively). These analyses would provide information on known sources of mercury emissions as well as identifying additional sources.

♦ ***Michigan should establish a regional air and precipitation monitoring network to determine the spatial distribution of airborne concentrations and deposition by mercury species across the state.*** These data would provide information on sources that are contributing to the deposition to the lakes.

♦ ***Michigan needs to determine if its soils are a net source or sink for mercury by applying state-of-the-art dry deposition measurement techniques.*** Vertical profiling as a function of time of day and season are needed to characterize this source/sink. This information is needed in order to quantify the impact of reducing anthropogenic mercury emission sources.

♦ ***There needs to be a national-scale investigation to obtain speciated mercury measurements in the plumes of all major mercury emission source types.*** This information is needed to determine which sources need to be controlled and the impact any control measure will have on observed mercury concentrations. Plume measurements are much more useful than stack measurements because some gaseous mercury-two in the stack is likely to condense out to particulate mercury-two after exiting the stack. Concurrent stack and plume measurements will help determine the rate of this transformation.

♦ ***There needs to be a national investigation designed and conducted on mercury mass balance in clouds to provide insight on the importance of nucleation scavenging versus in-cloud oxidation.*** Cloud chambers could be utilized to test the importance of in-cloud elemental mercury oxidation, gaseous mercury-two washout and particulate mercury-two nucleation scavenging. This needs to be done in order to determine which form of mercury should be controlled.

## ***Human Monitoring Data Needs***

♦ ***Michigan should periodically monitor its population, particularly pregnant women, to determine the current level of exposure to mercury and whether the exposure is changing.*** Hair and/or blood concentrations of mercury in the sensitive population should be measured at intervals not exceeding 5 years.

♦ *Michigan should reevaluate the threshold exposure value (currently 10 ppm to 20 ppm in hair) for methylmercury effects on a yearly basis.* This evaluation will permit the incorporation of newly acquired information that will increase the accuracy of the threshold estimate.

♦ *Michigan should conduct a yearly evaluation for mercury exposure in its population in relation to the most current threshold exposure value for methylmercury effects.* This evaluation will provide an estimate of current and projected health risks.

♦ *Michigan's current advisories for restricting consumption of mercury contaminated fish should be evaluated to determine if they are providing valid estimates of mercury intake for persons consuming freshwater fish.* The advisories should be developed using data obtained from a scientifically sound monitoring program. In addition, the monitoring program should also be designed to estimate the rate of change of mercury contamination in fish. Finally, the fish consumption advisories should be consistent with the current risk estimates for adverse health effect from methylmercury based heavily, but not entirely, on effects in the offspring of exposed pregnant women and should be changed to reflect changes in exposure estimates calculated from monitoring mercury levels in fish and humans.

#### **Education Needs**

♦ *Michigan needs to develop a statewide public information program on fish consumption advisories that would provide easy to read and understand pamphlets.* Despite fish consumption advisories that are provided by the state, a large segment of society remains unaware of potential dangers of eating contaminated fish from the state's freshwater lakes. Public awareness programs through schools, radio or television media would assist in this endeavor.

#### **Mercury Research Data Evaluation Needs**

♦ *Michigan should establish a central repository to collect and maintain information resulting from various state, federal, regional and international research investigations and information on various state, federal and international legislative initiatives.* The collected information should be developed into a comprehensive and up-to-date data base on mercury. Currently, there is no single state agency in Michigan which tracks all the various mercury research issues. For example, MDPH tends to be concerned with and tracks issues mostly dealing with the fish advisory and human health, while MDNR tends to be more concerned with and tracks issues related more with air and water regulatory issues as well as some issues on fish and wildlife. While this

approach has been useful for some of the concerns addressed in this report, it does not address all the concerns needed to develop a full understanding of the problems related to environmental and human health concerns associated with mercury. Similarly, there currently does not exist a central repository for the collection of various state and federal mercury legislative initiatives which may be useful for possible consideration in Michigan.

**♦ The Michigan Environmental Science Board should periodically (possibly once every 1 or 2 years) review and scientifically evaluate the accumulated mercury information and provide recommendations to the Governor based on new data and/or advancements in the understanding of mercury in the environment.**

As new research information becomes available, there will be a need for the state to scientifically evaluate the material in terms of its impact on ongoing and/or proposed state programs. The Michigan Environmental Science Board was created to advise the Governor and state agencies so designated by the Governor on matter relating to environmental protection and natural resources management matters.

## REFERENCES CITED

- Aastrup, M., J. Johnson, E. Bringmark, P. Bringmark and A. Iverfeldt. 1991. Occurrence and transport of mercury within a small catchment area. Water, Air and Soil Pollution, 56:155-167.
- Ammerman, L. and L. Van Maele. 1990. Removing Household Batteries from the Waste Stream: Problems and Opportunities, January 1990. Legislative Services Bureau, Lansing, Michigan. 9p.
- Balfour, R.L. 1992. The declining use of mercury in batteries. IN International Conference on Mercury as a Global Pollutant, May 31 - June 4, 1992 [Abstracts Only]. Electric Power Research Institute, U.S. Environmental Protection Agency, Vattenfall and Environmental Canada: AES, Monterey, California. 133p.
- Bornhausen, M., H.R. Musch, and H. Greim. 1980. Operant behavior performance changes in rats after prenatal methylmercury exposure. Toxicol. and Appl. Pharmacology, 56:305-310.
- Brigham, M.E. and P.L. Brezonik. 1992. Mercury cycling in lakes: development of analytical capabilities for ultra-trace mercury measurements, pp 2-1 - 2-15. IN Mercury in the St. Louis River, Mississippi River, Crane Lake and Sand Point Lake: Cycling, Distribution and Sources, April 1992. Report to the Legislative Commission on Minnesota Resources. Minnesota Pollution Control Agency, St Paul, Minnesota.
- Burton, B.K. [1992]. Comments on the August 1992 Task Force on Mercury Emissions Standards Setting, Preliminary Report, Volume II, Environmental and Health Issues. Correspondence to the New Jersey Department of Environmental Protection and Energy, September 11, 1992. Intergrated Waste Services Association, Washington, D.C. 7p.
- Clarkson, T.W. [1991]. [Comments on MDNR draft mercury criteria document]. Correspondence to Robert Sills, Michigan Department of Natural Resources, August 29, 1991. University of Rochester, Rochester, New York. 2p.
- Clarkson, T.W. 1990. Human health risks from methylmercury in fish. Environmental Toxicology and Chemistry, 9:957-961.
- Clement International Corporation. 1992. Draft Toxicological Profile for Mercury, October 1992. Contract No. 205-88-0608, Agency for Toxic Substance and Disease Registry, U.S. Dept. of Health and Human Serv., Atlanta, Georgia. 230p.

- Cole, H.S., A.L. Hitchcock and R. Collins. 1992. Mercury Warning: The Fish You Catch May Be Unsafe to Eat, A Study of Mercury Contamination in the United States, August 1992. Clean Water Fund, Clean Water Action, Washington, D.C. 61p.
- Compeau, G.C. and R. Bartha. 1985. Sulfate-reducing bacteria: principal methylators of mercury in anoxic estuarine sediment. Appl. Environ. Microbiol., 50:498-502.
- Connors, J.J. and H.T. Shacklette. 1975. Background Geochemistry of some Rocks, Soils, Plants and Vegetables in the Conterminous United States. U.S. Geological Survey Professional Paper 574-F. 168p.
- Cox, C., T.W. Clarkson, D.O. Marsh, L. Amin-Zaki, S. Tikriti and G. Myers. 1989. Dose-response analysis of infants prenatally exposed to methyl mercury: an application of a single compartment model to single-strand hair analysis. Environmental Research, 49:318-332.
- D'Itri, F.M. 1991. Mercury contamination-what we have learned since Minamata. Environ. Monitoring and Assessment, 19:165-182.
- Eisenreich, S.J. and W.M.J. Strachan (eds.). 1992. Estimating Atmospheric Deposition of Toxic Substances to the Great Lakes: An Update. Workshop at Canada Centre for Inland Waters, Burlington, Ontario, January 31 - February 21, 1992. Great Lakes Protection Fund and Environment Canada, Toronto, Canada.
- Elsner, J., B. Hodel, K.E. Suter, D. Oelke, B. Ulbrich, G. Schreiner, V. Cuomo, R. Cagiano, L.E. Rosengren, J.E. Karlsson and K.G. Haglid. 1988. Investigations of different approaches in behavioral teratology and correlation with neurochemical parameters. Neurotoxicol. and Teratology, 10:155-167.
- Evans, E. [1993]. Personal Communication to David Long, Michigan Environmental Science Board. Michigan Department of Natural Resources, Lansing.
- Evans, E., M. Wilson and W. Creal. 1991. Assessment of Mercury Contamination in Selected Michigan Lakes, 1987-90: Historical Trends, Environmental Correlates and Potential Sources. Report #MI/DNR/SWQ-91/106. Michigan Department of Natural Resources, Lansing.
- Fergusson, J.E. 1990. The Heavy Elements: Chemistry, Environmental Impact and Health Effects. Pergamon Press, New York, New York. 614p.
- Ferraro, F. [1992]. Letter to New Jersey Department of Environmental Protection and Energy, September 10, 1992. Wheelabrator Environmental Systems, Inc., Hampton, New Hampshire.

11p.

- Fitzgerald, W.F. and C.J. Watras. 1989. Mercury in surficial waters of rural Wisconsin lakes. The Science of the Total Environment, 87/88:223-232.
- Fitzgerald, W.F., R.P. Mason, G.M. Vandal and F. Dulac. 1992. Air-Water Cycling of Mercury in Lakes. IN International Conference on Mercury as a Global Pollutant, May 31 - June 4, 1992 [Abstracts Only]. Electric Power Research Institute, U.S. Environmental Protection Agency, Vattenfall and Environmental Canada: AES, Monterey, California. 133p.
- Forrester K.E. and R.W. Goodwin. 1989. Engineering management of MSW ashes: field empirical observations of concrete-like characteristics, pp 5B-15 - 5B-32. IN Brna, T.G. and R.K. Klicius (eds). Proceedings International Conference on Municipal Waste Combustion, April 11 - 14, 1989, Hollywood, Florida. Ministry of Supply and Service, Ottawa, Canada.
- Fong, W.G. [1993]. [Table showing FY 1991-92 mercury analysis results for 125 samples of tuna fish]. Personal Communication to Keith Harrison, Michigan Environmental Science Board, April 8, 1993. Chemical Residue Laboratory, Florida Department of Agriculture and Consumer Services, Tallahassee.
- Fouts, J. 1993. Personal Communication to Larry Fischer, Michigan Environmental Science Board. National Institute of Environmental Health Sciences.
- Frank, R., H. Lumsden, J.F. Barr, and H.E. Braun. 1983. Residues of organochlorine insecticides, industrial chemicals and mercury in eggs and tissues taken from healthy and emaciated common loons, Ontario, Canada, 1969-1980. Arch. Environ. Contam. Toxicol., 12:641-654.
- Greenberg, A., I. Wostenko, H. Chen, S. Krivanek, J.P. Butler, J. Held, P. Weiss and N.M. Reiss. 1992. Mercury in Air and Rainwater in the Vicinity of a Municipal Resource Recovery Facility in Northwestern New Jersey. Paper presented at the May 8, 1992 Air & Waste Management Association Meeting, Durham, North Carolina. 8p.
- Harada, Y. 1966. Congenital (or fetal) Minamata disease, pp 93-117. IN Katsanuma, M. (ed.). Minamata Disease, Study Group on Minamata Disease, Kumamoto Univ., Japan.
- Hesse, J.L. [1992]. [Comments made to the Michigan Environmental Science Board Mercury Panel], pp 14-16. IN Harrison, K.G. (ed.). Michigan Environmental Science Board Mercury Panel Meeting Minutes, Monday, December 14, 1992. Michigan Environmental Science Board, Lansing. 19p.



- Hoyer, M., C. Lamborg, G.J. Keeler and A. Hoffman. (In press). Measurements of atmospheric mercury in the Great Lakes basin. IN Huckabee, J. and C. Watras (eds.). Mercury as a Global Pollutant, Lewis Publishers, Ann Arbor, Michigan.
- Humphrey, H.E.B. 1974. Mercury Project - Update Report. Michigan Department of Public Health, Lansing. 6p.
- Hurley, J.P., C.J. Watras and N.S. Bloom. (In press). Mercury cycling in a northern Wisconsin seepage lake; the role of particulate matter in vertical transport. 9p.
- IJC. 1992. Sixth Biennial Report on Great Lakes Water Quality. International Joint Commission, Windsor, Ontario. 59p.
- IJC. 1990. Fifth Biennial Report on Great Lakes Water Quality. International Joint Commission, Windsor, Ontario. 60p.
- Iverfeldt, A. and O. Lindqvist. 1986. Atmospheric oxidation of elemental mercury by ozone in the aqueous phase, Atmos. Environ., 20:1567-1573.
- Jarabek, A.M. [1993]. [US EPA review comments on Volume II, Environmental and Health Issues, Task Force on Mercury Emissions Standards Setting Preliminary Report]. Correspondence to Dr. Alan Stern, New Jersey Department of Environmental Protection and Energy, January 18, 1993. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. 5p.
- Jensen, S. and A. Jernelov. 1969. Biological methylation of mercury in aquatic organisms. Nature (London), 223:753-754.
- Johansson, K., M. Aastrup, A. Andersson, L. Bringmark and A. Iverfeldt. 1991. Mercury in Swedish forest soils and waters - assessment of critical load. Water, Air and Soil Pollution, 56:267-281.
- Johansson, K. and A. Iverfeldt. 1992. The impact of increased Hg in soil on the transport of Hg to lakes in Sweden. IN International Conference on Mercury as a Global Pollutant, May 31 - June 4, 1992 [Abstracts Only]. Electric Power Research Institute, U.S. Environmental Protection Agency, Vattenfall and Environmental Canada: AES, Monterey, California. 133p.
- Jones, K.H. [1993]. A Review of the Preliminary Report: Volume 2, Environmental and Health Issues by the Task Force on Mercury Emissions Standard Setting of the New Jersey Department of Environmental Protection and Energy (September 1992), January 1993. Zephyr Consulting, Seattle, Washington. 20p.
- Jones, K.H. [1992]. Review of MDNR Mercury Impact Analysis of the Proposed Oakland WTE on Lower Trout Lake, December 10, 1992. Zephyr Consulting, Seattle, Washington. 7p.

- KBN Engineering & Applied Sciences, Inc. 1992. Mercury Emissions to the Atmosphere in Florida: Final Report, August 1992. Florida Dept. of Environmental Regulations, Tallahassee. 266p.
- Keeler, G.J. [1993]. Personal Communication to George Wolff, Michigan Environmental Science Board. School of Public Health, University of Michigan, Ann Arbor.
- Keeler, C.J., M.E. Hoyer and C.H. Lamborg. (In press). Measurements of atmospheric mercury in Great Lakes basin. IN Huckabee, J. and C. Watras (eds.). Mercury as a Global Pollutant, Lewis Publishers, Ann Arbor, Michigan.
- Kelley, T., J. Jones and G. Smith. 1975. Historical changes in mercury contamination in Michigan walleyes (Stizostedion vitreum vitreum). J. Fish. Res. Board Can., 32(10):1745-1754.
- Kjellstrom, T., P. Kennedy, S. Wallis, A. Stewart, L. Friberg, B. Lind, P. Wutherspoon, and C. Mantell. 1989. Physical and Mental Development of Children with Prenatal Exposure to Mercury from Fish, Stage 2, Interviews and Psychological Tests at Age 6. National Swedish Environ. Protection Board Report No. 3642, Solna, Sweden. 112p.
- Lamborg, C.H., M.E. Hoyer, G.J. Keeler and I. Olmez. (In press). Particulate phase mercury in the atmosphere, collection-analysis method development and applications. IN Huckabee, J. and C. Watras (eds.) Mercury as a Global Pollutant, Lewis Publishers, Ann Arbor, Michigan.
- Lathrop, R.C., P.W. Rasmussen and D.R. Knauer. 1991. Mercury concentrations in walleyes from Wisconsin (USA) lakes. Water, Air and Soil Pollution, 56:295-307.
- Lee, G.F. and R.A. Jones. 1992. Municipal Solid Waste Management in Lined, "Dry Tomb" Landfills: A Technologically Flawed Approach for Protection of Groundwater Quality. G. Fred Lee & Associates, El Macero, California. 68p.
- Leonard, D. [1992]. Comments on Draft MDNR Report on Mercury in Michigan's Environment - Causes and Extent of the Problem. Correspondence to the Michigan Department of Natural Resources, September 16, 1992. Detroit Edison, Detroit. 5p.
- Lindberg, S.E. [1993]. Personal Communication to George Wolff, Michigan Environmental Science Board. Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee.
- Lindberg, S.E., T.P. Meyers, G.E. Taylor, R.R. Turner and W.H. Schroeder. 1992. Atmosphere-surface exchange of mercury in a forest: results of modeling and gradient approaches. J. Geophys. Res., 97:2519-2528.

- Lindberg, S.E., R.R. Turner, T.P. Meyers, G.E. Taylor and W.H. Schroeder. 1991. Atmospheric concentrations and depositions of Hg to a deciduous forest at Walker Branch watershed, Tennessee. Water, Air and Soil Pollution, 56:577-594.
- Lindqvist, O. (ed). 1991. Mercury in the Swedish environment - recent research on causes, consequences and corrective methods. Water, Air and Soil Pollution, 55:1-261.
- Lodenius, M. 1992. Mercury in terrestrial ecosystems: a review. IN International Conference on Mercury as a Global Pollutant, May 31 -June 4, 1992 [Abstracts Only]. Electric Power Research Institute, U.S. Environmental Protection Agency, Vattenfall and Environmental Canada: AES, Monterey, California. 133p.
- Long, D.T. [1993]. Preliminary Report on Mercury in Sediments of Michigan for Mercury Panel of the Michigan Environmental Science Board, January 26, 1993. Michigan Environmental Science Board, Lansing. 14p.
- LSB. 1992. Mercury: Master of Illusion, Environmental Puzzle, June 1992. Science and Technology Division, Legislative Service Bureau, Lansing, Michigan. 43p.
- Marsh, D.O., T.W. Clarkson, C. Cox, G.J. Myers, L. Amin-Zaki and S. Al-Tikriti. 1987. Fetal methylmercury poisoning. Arch. Neurol., 44:1017-1022.
- Mayer-Schwinning, G. and E. Laibold. 1989. Basic process for cleaning flue gases from waste incineration plants. IN Brna, T.G. and R.K. Klicius (eds). Proceedings International Conference on Municipal Waste Combustion April 11-14, 1989, Hollywood, Florida. Ministry of Supply and Service, Ottawa, Canada.
- McKeown-Eyssen, G.E., J. Ruedy and A. Neims. 1983. Methyl mercury exposure in northern Quebec. II. Neurologic findings in children. Am. J. Epidemiol., 118:470-479.
- MDA. 1992. MDA Officials Warn Residents to Limit Consumption of Shark Meat, Press Release, February 4, 1992. Michigan Department of Agriculture, Lansing. 1p.
- MDNR. 1992a. Mercury and Other Metal in Bald Eagle Feathers and Other Tissues from Michigan, Nearby Areas of Minnesota, Wisconsin, Ohio, Ontario and Alaska, 1985-1989. Michigan Department of Natural Resources, Lansing. 6p.
- MDNR. 1992b. Michigan Fish Contaminant Monitoring Program, 1992 Annual Report [pages i-viii and 1-6]. Report #MI/DNR/SQA-92..., Michigan Department of Natural Resources, Lansing.

- MDNR. 1992c. Mercury in Michigan's Environment, Causes and Extent of the Problem, June 24, 1992 Draft. Michigan Department of Natural Resources, Lansing. 178p.
- MDNR. 1991. Michigan Fish Contaminant Monitoring Program, 1991 Annual Report [pages i-vi and 70-81]. Report #MI/DNR/SWA-91/273, Michigan Department of Natural Resources, Lansing.
- Mierle, G. 1990. Aqueous inputs of mercury to Precambrian Shield lakes in Ontario, Environmental Toxicology and Chemistry, 9:843-851.
- Moore, E. 1993. Report on the Management of Mercury-Containing Lamps (Fluorescent and High-intensity Discharge Lamps), January, 1993. Minnesota Office of Waste Management, St. Paul. 81p.
- Moser, H.D. and A.F. Voight. 1957. Dismutation of the mercurous dimer in dilute solutions. J. Am. Chem. Soc., 79:1837-1839.
- Nebel, K.L., D.M. White, C.R. Parrish, T.G. Zirkei, M.A. Palazzolo and M.S. Hartman. 1992. OMSS Field Test on Carbon Injection for Mercury Control, September 1992. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. USEPA 600/R-92-192. 150p.
- Neme, C. 1991. Electric Utilities and Long-Range Transport of Mercury and Other Toxic Air Pollutants, November 1991. Center for Clean Air Policy, Washington, D.C. 90p.
- NJDEPE. 1992. Task Force on Mercury Standard Setting Preliminary Report, September 1992. New Jersey Department of Environmental Protection and Energy, Trenton. 3 Vol. 332p.
- Olson, B.H. and R.C. Copper. 1976. Comparison of aerobic and anaerobic methylation of mercuric chloride by San Francisco Bay sediments. Water Res., 10:113-116.
- Porcella, D. [1992]. Presentation: Update on Mercury Research Program, December 14, 1992, p. 2-8. IN Harrison, K.G. (ed.) Michigan Environmental Science Board Mercury Panel Meeting Minutes, Monday, December 14, 1992. Michigan Environmental Science Board, Lansing, Michigan. 19p.
- Rothstein, R.A., B. Clemence and P.J. Stoller. 1991. Issues Associated with Environmental and Permit Evaluations of Mercury Emissions from Municipal Waste Combustors. Paper presented at the November 11-14, 1991 Air, Water and Waste Technologies Conference, Engineering Soc. of Detroit and Michigan, Detroit. 38p.
- Schmitt, C.J. and W.G. Brumbaugh. 1990. National contaminant biomonitoring program: concentrations of arsenic, cadmium,

- copper, lead, mercury, selenium and zinc in U.S. freshwater fish, 1976 - 1984. Arch. Environ. Contam. Toxicol., 19:731-747.
- Schneider, F. [1993]. Personal Communication to L.J. Fischer, Michigan Environmental Science Board. U.S. Food and Drug Administration, Detroit, Michigan.
- Schroeder, W.H., G. Yarwood and H. Niki. 1991. Transformation process involving mercury species in the atmosphere - results from a literature review. Water, Air and Soil Pollution, 55:653-666.
- Shieh, C.S. 1992. The specific role of waste-to-energy facilities in environmental cycling of mercury. IN International Conference on Mercury as a Global Pollutant, May 31 - June 4, 1992 [Abstracts Only]. Electric Power Research Institute, U.S. Environmental Protection Agency, Vattenfall and Environmental Canada: AES, Monterey, California. 133p.
- Silver S. and T.K. Misra. 1988. Plasmid-mediated heavy metal resistances. Ann. Rev. Microbiol., 42:717-743.
- Slemr, F. and E. Langer. 1992. Increase in global atmospheric concentrations of mercury inferred from measurements over the Atlantic Ocean. Nature, 355:434-437.
- Strunk, J. 1991. The Estraction of Mercury from Sediments and the Geachemical Partitioning of Mercury in Sediments from Lake Superior. Masters Thesis, Department of Geological Sciences, Michigan State University, E. Lansing.
- Summers, A.O. 1986. Organization, expression and evolution of genes for mercury resistance. Ann. Rev. Microbiol., 40:607-634.
- Summers, A.O. and S. Silver. 1978. Microbial transformation of metals. Ann. Rev. Microbiol., 32:637-672.
- Summers, A.O., J. Wireman, M.J. Vimy and F.L. Lorscheider. 1990. Increased mercury resistance in monkey gigival and intestinal bacterial flora after placement of dental "silver" fillings [Abstract Only]. Physiologist, 33:116.
- Swain, E.B., D.R. Engstrom, M.E. Brigham, T.A. Henning and P.L. Brezonik. 1992. Increasing rates of atmospheric mercury deposition in midcontinental North America. Science, 257:784-787.
- Swain, E.B. and D.D. Helwig. 1989. Mercury in fish from northeastern Minnesota lakes: historical trends, environmental correlates and potential sources. J. Minnesota Academy Sci., 55:103-109.

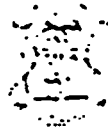
- Taylor, J.K. [1993]. Update on the Clean Air Act (CAA). Correspondence to the Michigan Environmental Science Board, February 2, 1993. Michigan Department of Natural Resources, Lansing. 4p.
- Taylor, J.K. [1992]. FYI-Lafarge Corporation's Mercury Emissions. Memorandum to Rick Johns, April 20, 1992. Michigan Department of Natural Resources, Lansing. 1p.
- Tietenberg, T. 1992. Environmental and Natural Resource Economics, 3<sup>rd</sup> edition. Harper Collins Pub., Inc., New York.
- Turner, M.D., D.O. Marsh, J. Chrispin-Smith, J.B. Ingles, T.W. Clarkson, C.E. Rubio, J. Chiriboga and C.C. Chiriboga. 1980. Methylmercury in populations eating large quantities of marine fish. Arch. Environ. Health, 35:367-375.
- USEPA. 1993a. EPA Issues Great Lakes Water Quality Guidance, Press Release, March 31, 1993. U.S. Environmental Protection Agency, Chicago, Illinois. 3p.
- USEPA. 1993b. EPA releases new regs for managing sludges. Solid Waste and Power, 7(1):6.
- USEPA. 1992. Characterization of Products Containing Mercury in Municipal Solid Waste in the United States, 1970 to 2000, April 1992. Office of Solid Waste, Washington D.C. EPA530-R-92-013. 135p.
- Van Maele, L. 1990. Household Battery Collection and Storage, March 1990. Legislative Services Bureau, Lansing, Michigan. 5p.
- Volland, C.S. 1992. Paper #92-40.1, Emissions of Volatile Heavy Metals from Medical Waste Incinerators, 16p. Paper presented at the 85<sup>th</sup> Annual Meeting & Exhibition, Kansas City, Missouri, June 21 - 26, 1992. Air & Waste Management Association, Pittsburgh Pennsylvania.
- Volland, C.S. 1991. Paper 91-35.1, Mercury Emissions from Municipal Solid Waste Combustion, 18p. Paper presented at the 84<sup>th</sup> Annual Meeting & Exhibition, Vancouver, British Columbia, June 16 - 21, 1991. Air & Waste Management Association, Pittsburgh, Pennsylvania.
- Warneck, P. 1988. Chemistry of the Natural Atmosphere. Academic Press, New York. 757p.
- Watras, C.J., N.S. Bloom, W.F. Fitzgerald, J.P. Hurley, D.P. Krabbenhoft, R.G. Rada and J.G. Wiener. 1989. Mercury in temperate lakes: a mechanistic field study [Abstract Only]. Verh. Internat. Verein Limnol., IVL 476 DA 43-6802.

- White, D.M. and A.M. Jackson. 1992. Technical Work Paper on Mercury Emissions from Waste Combustors. Minnesota Pollution Control Agency, St. Paul, Minnesota.
- White, D.M., K.L. Nebel, T.G. Brna and J.D. Kilgroe. 1992. Parametric Evaluation of Powdered Activated Carbon Injection for Control of Mercury Emissions from a Municipal Waste Combustor. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. USEPA 92-40.06. 16p.
- WHO. 1990. Environmental Health Criteria 101, Methylmercury. World Health Organization, Geneva, Switzerland. 143p.
- Widenman III, A.J. [1992]. Concentrations of Mercury in Coal - EPRI Version Technical & Engineering Services Report 92A23-01. Memorandum to M.F. Rodenberg, January 28, 1992. Detroit Edison, Detroit. 28p.
- Wiener, J.G. D.E. Powell and R.G. Rada. 1992. Mercury accumulation by fish in Wisconsin seepage lakes: relation to lake chemistry and acidification. IN International Conference on Mercury as a Global Pollutant, May 31 - June 4, 1992 [Abstracts Only]. Electric Power Research Institute, U.S. Environmental Protection Agency, Vattenfall and Environmental Canada: AES, Monterey, California. 133p.
- Wiener, J.G., W.F. Fitzgerald, C.J. Watras and R.G. Rada. 1990. Partitioning and bioavailability of mercury in an experimentally acidified Wisconsin lake. Environmental Toxicology and Chemistry, 9:909-918.
- Wiley, G.C. [1992]. Personal Communication to Sharon Picard, Michigan Environmental Science Board. Mercury Refining Co., Inc. Albany, New York.
- Wren, C.D. 1991. Cause-effect linkages between chemicals and populations of mink (Mustela vison) and otter (Lutra canadensis) in the Great Lakes basin. J. Toxicol. Environ. Health, 33:549-585.
- Ziff, S. and M.F. Ziff. 1992. Dental mercury - an environmental hazard. Bio-Probe Newsletter, 8(5):1-6.

**APPENDIX I**

*August 6, 1992 Letter from Governor John Engler*





STATE OF MICHIGAN  
OFFICE OF THE GOVERNOR  
LANSING

JOHN ENGLER  
GOVERNOR

August 6, 1992

Dr. Lawrence Fischer, Chair  
Michigan Environmental Science Board  
Michigan State University  
Institute for Environmental Toxicology  
C-231 Holden Hall  
East Lansing, Michigan 48824

Dear Dr. Fischer:

There is evidence that a significant number of Michigan's inland lakes and streams are contaminated with excess levels of mercury. Given that exposure to excessive concentrations of mercury is harmful to human health, and because mercury exists in nature, is used in manmade products, and is present in some wastes that must be disposed of in Michigan, I request the Michigan Environmental Science Board address this issue as its first task.

Specifically, I would like the Board to do the following:

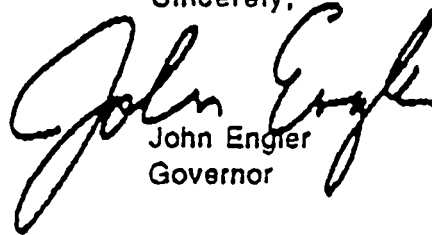
1. Compile existing data regarding the levels of mercury found in Michigan's environment and estimate the risk those levels pose to the health of Michigan's citizens.
2. To the extent possible, determine the sources of mercury found in Michigan's environment, the pathways by which mercury enters the environment, and the means by which humans are exposed to mercury.
3. Determine what state, federal, and international standards and abatement programs currently exist, and the status of any proposed state or federal regulations.
4. Propose and evaluate options for controlling or eliminating harmful emissions of mercury into the environment.
5. Recommend what further studies may be needed in order implement the above charges.

I am directing the Departments of Public Health and Natural Resources to fully cooperate with and support the Board's investigations.

Dr. Fischer  
Page Two  
August 6, 1992

When I issued Executive Order 1991-33, there was some concern expressed that the Open Meetings Act may not apply to the Board. Please assume that it does and conduct the business of the Board accordingly.

Sincerely,

A handwritten signature in black ink, appearing to read "John Engler". The signature is fluid and cursive, with the first name "John" being more prominent than the last name "Engler".

John Engler  
Governor

JE/CM/jll

cc: Keith Harrison  
Roland Harmes  
Vernice Davis Anthony  
Natural Resources Commission Members

**APPENDIX II**

**Michigan Environmental Science Board  
Mercury Panel**

**Annotated Bibliography**

**APPENDIX II. MICHIGAN ENVIRONMENTAL SCIENCE BOARD MERCURY PANEL  
ANNOTATED BIBLIOGRAPHY<sup>a</sup>.**

\_\_\_\_\_. 1992. International Conference on Mercury as a Global Pollutant, May 31 - June 4, 1992 [Abstracts Only]. Electric Power Research Institute, U.S. Environmental Protection Agency, Vattenfall and Environmental Canada: AES, Monterey, California. 133p. (MESB 10/21/92)<sup>b</sup>

Document contains abstracts of papers presented at the May 31 - June 4, 1992 Monterey, California conference on mercury. Topics addressed include, fish bioaccumulation, atmospheric chemistry and measurements, atmospheric cycling (aquatic and terrestrial), health, terrestrial accumulation and effects, methylation, inter-media transport, terrestrial transport and turnover, cycling in marine and estuarine systems, mitigation, mitigation and economics, freshwater systems, analytical chemistry and modelling.

Aastrup, M., J. Johnson, E. Bringmark, P. Bringmark and A. Iverfeldt. 1991. Occurrence and transport of mercury within a small catchment area. Water, Air and Soil Pollution, 56:155-167. (MESB 3/24/93)

To contribute to the understanding of mercury flow to forest lakes the storage of mercury in the soil of a catchment was quantified, the transport of mercury from the recharge area to the discharge area was studied and a mass balance for different soil horizons was calculated. The transport of mercury in soil, ground and stream water was estimated using water flows from a hydrological model and by determining mercury in water sampled with a clean procedure. The estimate for the annual mercury flux out of the till overburden in the catchment was 3.4 g/km<sup>2</sup>. The annual flux was reduced to 1.3 g/km<sup>2</sup> in the stream, indicating interception in a lake. The transport was predominantly taking place in the upper 50 cm of the soil. The storage of mercury in the soil was 8.8 kg/km<sup>2</sup>, which is large compared to the flux. A net accumulation, amounting to 80% of the mercury deposition, is almost entirely located to the mor layer.

Ammerman, L. and L. Van Maele. 1990. Removing Household Batteries from the Waste Stream: Problems and Opportunities, January 1990. Legislative Service Bureau, Lansing, Michigan. 9p. (MESB 12/9/92)

Household batteries constitute 19% of household hazardous waste. Mercury and cadmium are the sources of greatest concern. Battery collection has generally been a response to excessive heavy metals in incinerator emissions, although it may be economically feasible to recover some of the metals. The report lists types and uses of household batteries and the hazardous substances they contain. It enumerates current battery collection and recycling programs, in

---

<sup>a</sup>The bibliography represents most, but not all, of the resource documents which were reviewed by the Michigan Environmental Science Board Mercury Panel.

<sup>b</sup>Michigan Environmental Science Board Citation Reference Number.

Europe and America, including two Michigan cities. Collection methods are discussed. As of January 1990, there were two companies processing batteries to reclaim mercury, but operating procedures of both were under question. The paper concludes that while household batteries pose special risks of increased pollution in solid waste landfills and incinerators, there are safety problems involved in collection and storage and recycling may not be economically feasible. Most batteries currently collected are either being stockpiled or disposed of as hazardous waste.

Balfour, R.L. 1992. The declining use of mercury in batteries. IN International Conference on Mercury as a Global Pollutant, May 31 - June 4, 1992 [Abstracts Only]. Electric Power Research Institute, U.S. Environmental Protection Agency, Vattenfall and Environmental Canada: AES, Monterey, California. 133p. (MESB 10/21/92)

Use of mercury in dry cell battery production has sharply declined in recent years, and further declines are expected in the future. According to the U.S. Bureau of Mines, mercury consumption in U.S. battery products declined by 81% from 1984 to 1989, and declined even further in 1990. Comparable reductions have occurred in European and Japanese battery production.

Bornhausen, M., H.R. Musch, and H. Greim. 1980. Operant behavior performance changes in rats after prenatal methylmercury exposure. Toxicol. and Appl. Pharmacology, 56:305-310. (MESB 3/26/93)

Methylmercury chloride in doses of 0.005-0.05 mg/kg was force fed to pregnant rats at the sixth, seventh, eighth, and ninth day after conception. When 4 months of age, the offspring were tested in lever boxes with the operant conditioning program "differential reinforcement of high rates" (DRH). Food reinforcement was made contingent to the fulfillment of performance requirements which were incrementally increased in 3 steps: In the first test session the animals were required to press the lever twice in 1 second for one food reward (DRH 2/1); in the following test sessions four lever presses in 2 seconds (DRH 4/2) and eight lever presses in 4 seconds (DRH 8/4) were required for one reward, respectively. Animal performance in this behavioral paradigm was expressed as the group mean ( $n = 10$ ) of the ratio of correct; i.e., rewarded, responses to total lever presses per session. Methylmercury chloride-induced performance deficits were found in the  $4 \times 0.05$  and  $4 \times 0.01$  mg/kg dose groups. DRH-learning differences were ascertained by an analysis of variance. The lowest effective dose of  $4 \times 0.01$  mg/kg points to operant conditioning techniques as a suitable tool in environmental toxicology.

Brigham, M.E. and P.L. Brezonik. 1992. Mercury cycling in lakes: development of analytical capabilities for ultra-trace mercury measurements, pp 2-1 - 2-15. IN Mercury in the St. Louis River, Mississippi River, Crane Lake and Sand Point Lake: Cycling, Distribution and Sources, April 1992. Report to the Legislative Commission on Minnesota Resources. Minnesota Pollution Control Agency, St Paul, Minnesota. (MESB 3/19/93)

The paper describes the improved analytical methods used to study mercury cycling in Minnesota lakes. Preliminary data are presented on water-column mercury concentrations to demonstrate the sensitivity of the methods. These

data are offered in the context of a general discussion on mercury cycling in lakes, rather than as a comprehensive study. The ultra-trace detection system assembled in the study offers greatly improved detection of methylmercury and total mercury species. While mercury in the environment has been studied for many years, accurate determination at ultra-trace levels ( $<0.1$  ng/l) is a new capability that promises to greatly improve the understanding of mercury cycling in natural waters. Ultra-trace analytical techniques are well suited to studying atmospheric mercury deposition and cycling within lakes. Integrating this approach with analysis of dated lake sediment cores will provide useful information on the sources, spatial and temporal trends of mercury deposition to lakes, and the factors that determine the extent of mercury bioaccumulation in the upper trophic levels of the food webs in these lakes.

Bulkley, J.W. [1993]. Draft Response to Directions from Governor Engler Dated August 6, 1992, January 26, 1993. Michigan Environmental Science Board, Lansing. 3p. (MESB 1/27/93)

Paper reviews data which have been accumulated regarding mercury sources and pathways, and the associated risk to humans and wildlife. It also discusses the current status of the standard for Acceptable Daily Intake and how its proposed lowering may impact on Michigan's Fish Advisory. Several recommendations are offered regarding point source discharges, the need to investigate mercury loading from coal-fired power plants, supporting legislation to further limit mercury in batteries and packaging materials and obtaining additional information from the USEPA on several ongoing investigations.

Burton, B.K. [1992]. Comments on the August 1992 Task Force on Mercury Emissions Standards Setting, Preliminary Report, Volume II, Environmental and Health Issues. Correspondence to the New Jersey Department of Environmental Protection and Energy, September 11, 1992. Integrated Waste Services Association, Washington, D.C. 7p. (MESB 1/27/93)

Correspondence criticizes the New Jersey report for analysis which are not biologically plausible and not supported in the scientific literature. Burton recommends that New Jersey adopt the USEPA's reference dose for methylmercury and that this be applied only to mercury concentrations in fish which are actually attributable to emissions from waste-to-energy facilities. If this is unacceptable, New Jersey should strongly consider the adoption of the reference dose range mentioned by Clarkson (1990). Regarding canned tuna, Burton recommends that New Jersey start with a hazard index of 1 and back-calculate the stack emission level which could cause this to be exceeded [references are provided for argument].

Cairns, J. and R.M. Harrison (eds.). (In press). Statement from the work session on chemically induced alterations in sexual development: the wildlife/human connection. IN Chemically Induced Alterations in Sexual Development: The Wildlife/Human Connection. Elsevier Applied Pub., Ltd., London. (MESB 1/27/93)

Statement concludes that a large number of man-made chemicals that have been

released into the environment, as well as a few natural ones (e.g., mercury), have the potential to disrupt the endocrine system of animals, including humans. The pattern of effects vary among species and among compounds. Four general points are made: (1) the chemical of concern may have entirely different effects on the embryo, fetus or perinatal organism than on the adult, (2) the effects are most often manifested in offspring, not in the exposed parent; (3) the timing of exposure in the developing organism is crucial in determining its character and future potential, and (4) although critical exposure occurs during embryonic development, obvious manifestations may not occur until maturity. Many areas of needed research are suggested.

Center for Disease Control. 1991. Acute and chronic poisoning from residential exposures to elemental mercury-Michigan 1989-1990. Morbidity and Mortality Weekly Report, 40(23):393-395. (MESB 2/8/93)

Report describes 2 of 8 episodes of elemental mercury exposure in private residences or schools in the U.S. which were reported to the agency for Toxic Substances and Diseases Registry during the period, May 1989-November 1990. Both episodes occurred in Michigan.

Center for Disease Control. 1990. Mercury exposure from interior latex paint-Michigan. Morbidity and Mortality Weekly Report, 39(8):125-126. (MESB 2/8/93)

Report describes an episode of mercury poisoning in a 4 year old Michigan boy as a result of prolonged exposure to latex paint in his home. Analysis of the paint showed a concentration of 930-955 ppm mercury. The USEPA limit for mercury as a paint preservative is 300 ppm. Seventeen gallons of paint had been applied to the interior of the home during the first week in July. During July the windows had been kept closed because the house was air conditioned.

Center for Disease Control. 1989. Elemental mercury vapor poisoning-North Carolina. Morbidity and Mortality Weekly Report, 38(45):770-772 & 777. (MESB 2/8/93)

Report describes an episode of chronic mercury poisoning of a 3 year old North Carolina boy. A mercury vapor analyzer detected a mercury concentration of 20 mg/m<sup>3</sup>-60 mg/m<sup>3</sup> in five rooms and two bathrooms of the boy's home. The boy's bedroom registered 55 mg/m<sup>3</sup> (range: 30 mg/m<sup>3</sup>-140 mg/m<sup>3</sup>). Dust from the vacuum cleaner bag registered 4,400 ppm, and carpet samples had concentrations of 0.8 ppm-638 ppm. Reported cases of nonoccupational elemental mercury vapor poisoning are relatively rare. Acute cases usually result from inhalation of high concentrations of mercury vapor, which is produced when the metal is heated in an enclosed space.

Clark, T.L. [1992]. Current Research On Mercury In the Atmosphere. December 14, 1992. Paper presented to the Michigan Environmental Science Board. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. 4p. (MESB Minutes 12/14/92)

The USEPA is currently adapting two existing atmospheric models to simulate

mercury emission and deposition processes. The Regional Lagrangian Model of Air Pollution will produce monthly to annual fields of mean air concentration and wet and dry deposition amounts across a nested U.S. grid domain, with spatial resolution ranging from 40 to 200 kms. MESOPUFF-II will produce monthly to annual fields across a much finer spatial scale within and near major metropolitan areas, with the first test planned for the Detroit-Windsor area. Results of both models will be available in late 1993. Clark describes additional work needed before the models can be used for regulatory assessments as well as additional work required to provide input data required by the models. A speciation profile for major European mercury sources used by Josef Pacyna is also presented.

Clarkson, T.W. [1991]. [Comments on MDNR draft mercury criteria document]. Correspondence to Robert Sills, Michigan Department of Natural Resources, August 29, 1991. University of Rochester, Rochester, New York. 2p. (MESB 4/8/93)

Clarkson comments of mercury risk analysis prepared by MDNR. He is critical of the application of safety factors to LOAELs and NOAELs.

Clarkson, T.W. 1990. Human health risks from methylmercury in fish. Environmental Toxicology and Chemistry, 9:957-961. (MESB 3/26/93)

Human health risks from methylmercury in fish are evaluated in terms of dose-response relationships for both adult and prenatal human exposures. Specifically, information has become available from 3 independent epidemiological studies indicating that methylmercury levels in the mother during pregnancy predict the probability of adverse effects in her offspring. The mercury levels in the mother are measured as concentration in head hair which in turn is an excellent predictor of blood concentration. The adverse effects in the offspring take the form of psychomotor retardation. These dose-response relations along with a one-compartment kinetic model for methylmercury accumulation in humans is used to estimate minimum toxic daily intakes; these are, for nonpregnant adults, 4,300 ng mercury/kg/day body weight/day and about 600 to 1,100 ng mercury/kg/day for pregnant adults. These values assume continuous exposure until the individual has attained steady state balance with respect to the body burden of methylmercury. This will take up to 1 year in most cases.

Clement International Corporation. 1992. Draft Toxicological Profile for Mercury, October 1992. Contract No. 205-88-0608, Agency for Toxic Substance and Disease Registry, U.S. Dept. of Health and Human Serv., Atlanta, Georgia. 230p. (MESB 12/21/92)

Draft report provides information on the health effects, chemical and physical properties, potential for human exposure, analytical methods, regulations and advisories, and the production import/export, use and disposal of mercury.

Clement Risk Assessment Division. 1992. Understanding the Sources, Trends and Impacts of Mercury in the Environment, November 17, 1992. Prepared for Integrated Waste Services Association, Washington, D.C. 42p. (MESB 2/4/93)



Report constitutes an extensive literature review on sources of mercury, mercury in the environment, mercury and municipal waste combustion facilities on mercury related health impacts. Among the conclusions reached, the report suggests that, (1) natural sources account for 40-65% of annual mercury emissions, (2) current municipal waste combustion facilities account for less than 1% of annual mercury emissions, (3) about 1% of the total mercury in aquatic sediments is converted to organic methylmercury, (4) control technologies can remove 50-90% of the mercury in the stack gas, (5) no direct correlations have been established between elevated fish tissue concentrations and municipal waste combustion mercury emissions, (6) risk assessment studies repeatedly show that mercury emissions from modern waste-to-energy facilities do not cause adverse impacts in the local area to public health, aquatic life or the food chain; (7) mercury reducing efforts should target all major contributing sources and incentives should be established to encourage mercury reduction in products and source separation, and (8) public education programs regarding purchasing and disposing of mercury - containing products should be widely implemented.

Cole, H.S., A.L. Hitchcock, and R. Collins. 1992. Mercury Warning: The Fish You Catch May Be Unsafe to Eat, A Study of Mercury Contamination in the United States, August, 1992. Clean Water Fund, Clean Water Action, Washington, D.C. 61p. (MESB 12/15/92)

The reports discusses the impacts of the mercury on health and wildlife, provides a detailed listing of man-made and natural mercury sources, proposes the cause(s) of the mercury problem and critiques the federal government's record in regard to mercury. The report also offers five multi-part recommendations: (1) reduce public exposure to mercury through, (a) a federally-controlled and funded program to warn populations at risk, (b) the establishment of a stricter FDA standard for fish, (c) the development of a uniform national standard for fish advisories and (d) the development of uniform federal/state fish testing programs; (2) reduce emissions from incinerators through (a) a moratorium on new solid waste incinerator capacity, (b) the establishment of stricter emission standards on existing solid waste incinerators, (c) the establishment of local collection systems for household hazardous waste and products containing mercury and (d) the establishment of a moratorium on hazardous and medical waste incinerators; (3) reduce emissions from coal-fired power plants through (a) a moratorium on new construction of coal-fired plants, (b) the establishment of stricter emission standards on existing plants and (c) the rejection of the President's proposed National Energy Strategy; (4) reduce and eliminate mercury uses through, (a) banning the frivolous use of mercury in such items as toys, (b) the phase-out of the use of mercury for non-essential purposes such as golf course fungicides, (c) further reduction of the level of mercury in batteries and the promotion of the replacement of mercury oxide batteries with zinc oxide or other types of batteries, (d) the requirement of the use of less mercury in fluorescent lights and recovery of what mercury is use in the lights and (e) the discontinuance of the sales of mercury from government stockpiles; and (5) obtain critical information on mercury use and disposal through, (a) expanding the toxic release inventory created by the 1986 Community Right-to-Know Act, (b) initiating local community garbage audits to determine the amount of mercury and other toxics contained in municipal waste, (c) updating the USEPA

1973 mass balance study and (d) increasing the funding of government and independent scientist research.

Compeau, G.C. and R. Bartha. 1985. Sulfate-reducing bacteria: principal methylators of mercury in anoxic estuarine sediment. Appl. Environ. Microbiol., 50:498-502. (MESB 3/15/93)

Substrate-electron acceptor combinations and specific metabolic inhibitors were applied to anoxic saltmarsh sediment spiked with mercuric ions in an effort to identify, by a direct approach, the microorganisms responsible for the synthesis of hazardous monomethylmercury. 2-Bromoethane sulfonate (30 mM), a specific inhibitor of methanogens, increased monomethylmercury synthesis, whereas sodium molybdate (20 mM), a specific inhibitor of sulfate reducers, decreased mercuric ion methylation by more than 95%. Anaerobic enrichment and isolation procedures yielded a Desulfovibrio desulfuricans culture that vigorously methylated mercuric ions in culture solution and also in samples of presterilized sediment. The mercuric ion methylation activity of sulfate reducers is fully expressed only when sulfate is limiting and fermentable organic substrates are available. To date, sulfate reducers have not been suspected of mercuric ion methylation. Identification of these bacteria as the principal methylators of mercuric ions in anoxic sediments raises questions about the environmental relevance of previous pure culture-based methylation work.

Cook, R.J. [1987]. Solid and Hazardous Waste Incineration, An Analysis for Citizens and Policymakers, Pre-publication Draft. Kalamazoo College, Kalamazoo, Michigan. 76p. (MESB 2/22/93)

The document condenses fairly complex incineration and waste management/disposal issues into a readable format to present the advantages, disadvantages and uncertainties of incineration as a waste disposal option. The topics discussed include health and environmental concerns (air emissions, residuals, transportation and storage, operational safety, effects on surroundings, and health risk assessment), effectiveness (waste reduction, reliability, and economics) and alternatives to incineration. A additional topic in the report discusses the incineration technologies and experiences of several western European countries.

Cox, C. [1993]. [Four graphs showing trends in mercury contamination in Lake St. Clair sport fish, 1970-1991]. Correspondence to John Hesse, Michigan Department of Public Health, January 6, 1993. Ministry of the Environment, Toronto, Canada. 6p. (MESB 1/27/93)

Correspondence includes five graphs: Lake St. Clair walleye mean annual mercury 1970-1991, Lake St. Clair 1970-1990 mercury in northern pike, Lake St. Clair 1970-1990 mercury in channel catfish, Lake St. Clair 1970-1990 mercury in smallmouth bass and Lake St. Clair 1970-1991 mercury in yellow perch.

Cox, C., T.W. Clarkson, D.O. Marsh, L. Amin-Zaki, S. Tikriti and G. Myers. 1989. Dose-response analysis of infants prenatally exposed to methyl mercury: an application of a single compartment model to single-strand hair analysis. Environmental Research, 49:318-332. (MESB 3/19/93)

A new method of estimating fetal exposure is used in a dose-response analysis of data from the 1971 outbreak of methylmercury poisoning in rural Iraq. An X-ray fluorescence instrument for the measurement of single strands of human hair was employed to obtain longitudinal profiles recapitulating fetal exposure. Logit and hockey-stick models as well as nonparametric smoothing are used to describe data on delayed development and central nervous system abnormality.

Delfino, J.J. 1992. Assessment of Mercury Concentrations in Soils and Sediment Samples from the Everglades Wetland System and Implications of Natural and Anthropogenic Factors on Accumulations of Mercury in Wetlands, October 6, 1992. Quarterly Progress Report to the Florida Department of Environmental Regulation, Tallahassee. 70p. (MESB 1/12/93)

Extensive sediment core and water quality mercury sample data are presented. Also, graphs showing mercury concentration in core samples as a function of year of deposition are presented. In most instances, mercury concentration in the sediments increased dramatically from around 1950 on. Methods and results of three methodologies for the determination of total mercury and total organic mercury are discussed.

Denison, R. [1993]. Data on Heavy Metal Concentrations in Actual Field Leachate from MSW Incinerator Ash Monofills - Updated from August 24, 1992 Version. Memorandum to Interested Parties, January 8, 1993. Environmental Defense Fund, Washington, D.C. 10p. (MESB 1/29/93)

Summary of data on the concentrations of cadmium, chromium, lead and mercury in the leachate collected from various municipal solid waste incinerator ash mono-fills around the U.S. is presented. Illustrates that ash leachate frequently contains levels of one or more of these toxic heavy metals that exceed, in some cases by considerable amounts, their respective federal drinking water standards.

D'Itri, F.M. 1991. Mercury contamination-what we have learned since Minamata. Environ. Monitoring and Assessment, 19:165-182. (MESB 3/26/93)

Atmospheric cycling of mercury and other pollutants has become a major concern as industrialized countries have eliminated point discharges, sometimes by relocating the industries to underdeveloped and developing countries where point sources have become problems. Such circumventions may be to no avail in the long run as pollution continues to elevate levels of methylmercury in fish in waterways that are remote from direct contamination as well as where the source can be readily identified. Much has been learned about the cycling of mercury in the environment since human disabilities and deaths at Minamata, Japan, initially drew attention to the problem of methylmercury poisoning from consumption of contaminated seafood in the 1950's. In that instance, methylmercury produced industrially concentrated to toxic levels in fish. As this manufacturing process was not used outside Japan, concern did not become immediate in other developed nations until the 1960's when it was established that mercury was not only biomethylated by microorganisms but also biomagnified through the food chain. Point sources to the waterways may have been eliminated too late to return the levels in fish to background because

of the geochemical cycling of mercury through the environment. Despite decreases in domestic, industrial and agricultural point sources releases over the last 2 decades, large quantities from non-point sources such as fossil fuel combustion, smelters, and incinerators are still being released. Much of this mercury is transported from the atmosphere to aquatic ecosystems and stored in sediments until it is again released to the water and atmosphere.

Dunaskiss, M. [1992]. Senate Bill 795. Presentation to the Michigan Environmental Science Board, September 14, 1992. Lansing, Michigan. 2p. (MESB Minutes 9/11/92)

Proposed bill to create a new law to provide that, beginning on March 1, 1992, a permit to construct or install a municipal solid waste incinerator could not be issued if the incinerator would be located within a six-mile radius of any portion of an inland lake in which any fish sample from the preceding six years had had 0.5 ppm, or more, of mercury. In addition, a permit could not be issued unless the applicant demonstrated to the satisfaction of the Michigan Department of Natural Resources that no adverse impact from mercury would be evident in an inland lake within a zone defined by the projected plume of emissions from the incinerator and a point within 12 miles of it [Bill was not passed].

East, K. [1992]. Mercury Levels in Lakes in Oakland County. Memorandum to Senator Mat Dunaskiss. Legislative Service Bureau, Lansing, Michigan. 12p. (MESB Minutes 9/11/91)

Presents Michigan Department of Public Health data summary of mercury in fish from inland lakes tested through 1990. Samples were collected in 6 lakes in Oakland County from 1987 through 1990. Although a northern pike caught in Orchard Lake in 1989 had the second highest mercury level ever recorded in an inland lake in Michigan, there have been no consumption advisories issued for Oakland County lakes.

Elsner, J., B. Hodel, K.E. Suter, D. Oelke, B. Ulbrich, G. Schreiner, V. Cuomo, R. Cagiano, L.E. Rosengren, J.E. Karlsson and K.G. Haglid. 1988. Investigations of different approaches in behavioral teratology and correlation with neurochemical parameters. Neurotoxicol. and Teratology, 10:155-167. (MESB 3/26/93)

Five laboratories collaborated in the evaluation of detection limits of different testing concepts in behavioral teratology. In one laboratory, rat dams were treated by gavage with five doses of methylmercury (0.0, 0.025, 0.05, 0.5, and 5.0 mg/kg/day). The treatment period was restricted to days 6 to 9 of gestation. The usual reproduction parameters were assessed in the dams. The offspring (88-99 per group) were subjected to a routine developmental and behavioral testing battery. After completion of these tests, random samples of the animals were further investigated in 4 other laboratories using the following techniques: auditory startle habituation, visual discrimination and figure-8 activity monitor; wheel-shaped activity monitor and spatial alternation operant conditioning; two-compartment locomotor activity, passive avoidance and male ultrasonic vocalization during sexual behavior; assays of the weight of different effects were noted in

ascending dose sensitivity order: delayed vaginal opening; increased and more variable passiveness in spatial alternation; impaired swimming behavior, increased GFA protein concentration in the cerebellar vermis; increased auditory startle amplitude, decreased intertrial interval pokes in the visual discrimination test, increased percentage of visits impassive area of figure-8 activity monitor, increased path iteration frequencies and decreased local activity in the wheel-shaped activity monitor, decreased locomotor activity in the two-compartment monitor, increased cerebellar vermis weight, and decreased S-100 protein in the hippocampus. Therefore, this study showed comparable sensitivities for the behavioral testing battery, for some automated multiparametric test systems and for the neurochemical assays.

Ferraro, F. [1992]. Letter to New Jersey Department of Environmental Protection and Energy, September 10, 1992. Wheelabrator Environmental Systems, Inc., Hampton, New Hampshire. 11p. (MESB 10/13/92)

Correspondence critiques the New Jersey preliminary report on setting a standard for mercury (see NJDEPE, 1992b). The author is part of the Task Force who has responsibility for the report. The author cites numerous problems with the report's use of insufficient and misinterpreted data to draw conclusions. The author suggests that a Task Force minority report might need to be written should the final report be accepted without adequately addressing in particular, the health effects concerns, but also the problems and changes mentioned in his letter. Two of the stronger and more encompassing problems noted by author are: (1) the report relied on insufficient, outdated and unevaluated data and information to propose a mercury emission limitation and (2) the report incorrectly states that municipal solid waste combustion sources account for 40% of the mercury emissions (the correct value should be closer to 1%).

Fischer, L.J. [1993]. Discussion Document, Recommendations on Mercury in Michigan's Environment, January 26, 1993. Michigan Environmental Science Board, Lansing. 5p. (MESB 1/27/93)

Paper discusses human and wildlife risks from mercury exposure, protection from methylmercury effects, sources and pathways for mercury in Michigan and options for controlling or eliminating harmful emissions.

Fisher L. and Demers, R. [1992]. Methylmercury Exposure Conclusions Relative to Human Health, December 14, 1992. Michigan Environmental Science Board, Lansing. 7p. (MESB Minutes 12/14/92)

Fischer and Demers concluded that 100 ppm of methylmercury in human hair can be considered a Lowest Observable Adverse Effect Level for human fetal exposure, based on data from Japan and on data from an Iraqi mercury poisoning episode. Applying a safety factor of 10 produces an estimated No Observable Effect Level of 10 ppm in hair, which is the level adopted by the World Health Organization and supported by Cox's analysis of the Iraq data, as well as data on fish eaters in Quebec, and by animal studies. The authors conclude that at 0-10 ppm of methylmercury in hair there is no health concern known at present, at 11-20 ppm there are no likely effects, but precautions should be taken, at 21-100 ppm exposure restrictions should be made, and at 100+ ppm and

exposure reduction is necessary and treatment considered. Data from a Michigan Department of Public Health study on fish eating adults from Algonac and Grand Haven, Michigan indicated that persons eating fish from Lake St. Clair at the highest rate had mean blood levels of total mercury of 77.7 ppb, equivalent to 19 ppm in hair. If the threshold is really in the 10 to 20 ppm range and fish eaters can get close to 20 ppm, there is a low margin of safety. Additional data are needed on trends in the human and wildlife populations.

Fitzgerald, W.F. and C.J. Watras. 1989. Mercury in surficial waters of rural Wisconsin lakes. The Science of the Total Environment, 87/88:223-232. (MESB 3/19/93)

As part of an ongoing program to investigate mechanisms regulating the aquatic biogeochemistry of mercury, unfiltered surface waters of 8 rural lakes in northcentral Wisconsin were collected and analyzed for reactive and total mercury. Samples were collected during autumn mixis using ultra-clean, trace-metal-free protocols which have been applied successfully in the marine environment. Results indicate that mercury concentrations are considerably lower than previously reported, and approach levels observed in remote ocean waters. Concentrations of reactive mercury ranged from 0.7 to 2.9 pM in the 8 lakes studied. Total mercury ranged from 4.7 to 9.7 pM in four of the lakes. Although the data set is limited, these concentrations are 20-100 times lower than previous estimates for lakes in the region. The results reemphasize the importance of uncompromised clean laboratory protocols in the collection and analysis of trace constituents in natural waters. They also imply a reevaluation of ideas regarding the sources and distribution of mercury in lakes.

Fitzgerald, W.F., R.P. Mason, G.M. Vandal and F. Dulac. 1992. Air-Water Cycling of Mercury in Lakes. IN International Conference on Mercury as a Global Pollutant, May 31 - June 4, 1992 [Abstracts Only]. Electric Power Research Institute, U.S. Environmental Protection Agency, Vattenfall and Environmental Canada: AES, Monterey, California. 133p. (MESB 3/19/93)

The authors report on their ongoing mercury investigations in north central Wisconsin. The authors are specifically investigating tropospheric cycling, deposition and air-water exchange of mercury in lacustrine environments. In general, the results of their ongoing investigation strengthen their hypotheses regarding: (1) the preeminence of the atmospheric particulate mercury cycle in delivering mercury to aquatic systems, (2) the preminence of mercury-zero in the processes controlling the behavior and fate of mercury in natural waters, and (3) the mercury-two substrate biogeochemistry as a unifying physiochemical paradigm.

Fong, W.G. [1993]. [Table showing 1991-92 mercury analysis results for 125 samples of tuna fish]. Personal communication to Keith Harrison, Michigan Environmental Science Board, April 8, 1993. Chemical Residue Laboratory, Florida Department of Agriculture and Consumer Services, Tallahassee. (MESB 4/8/93)

Table presents the Florida Department of Agriculture and Consumer Services analysis of 125 samples of tuna fish for mercury during the period 1991-1992. The average level of mercury found in the samples was 0.31 ppm; the range was 0.13 ppm to 0.76 ppm.

Forrester, K.E. and R.W. Goodwin. 1989. Engineering management of MSW ashes: field empirical observations of concrete-like characteristics, pp 5B-15 - 5B-32. IN Brna, T.G. and R.K. Klicius (eds.). Proceedings International Conference on Municipal Waste Combustion, April 11-14, 1989, Hollywood, Florida. Ministry of Supply and Service, Ottawa, Canada. (MESB 2/2/93)

The paper reported that: (1) 10% Portland Cement added to raw municipal solid waste ash will achieve liner-like permeabilities ranging from  $7.5 \times 10^{-7}$  cm/sec to  $2.9 \times 10^{-7}$  cm/sec, depending on permeability test method; (2) permeabilities of 6.6% Portland Cement and raw ash varied from  $4.15 \times 10^{-7}$  cm/sec to  $2.0 \times 10^{-7}$  cm/sec, depending on test method; and (3) 6.6% lime and municipal solid waste ash achieved permeability of  $2.66 - 6.4 \times 10^{-6}$  cm/sec reducing the untreated ashes permeability by an order of magnitude suggesting a lime-based pozzolanic reaction. According to the authors, the relatively low permeability of the final products reduces the leachable surfaces and minimizes the solubility of heavy metal components of the waste.

Frank, R., H. Lumsden, J.F. Barr, and H.E. Braun. 1983. Residues or organochlorine insecticides, industrial chemicals and mercury in eggs and tissues taken from healthy and emaciated common loons, Ontario, Canada, 1969-1980. Arch. Environ. Contam. Toxicol., 12:641-654. (MESB 3/26/93)

Between 1968 and 1980, 98 eggs were collected from active nests of the common loon (Gavia immer) in Ontario. Residues of  $\Sigma$ DDT and PCB declined over this period while dieldrin and mercury appeared unchanged. Eggs collected in 1969 and 1970 had significantly thinner shells than eggs from a collection made before 1947. Between 1969 and 1979, 215 common loon carcasses were collected across Ontario, the result of having been drowned or shot or having died of diseases or unknown causes. Chemical analyses of 174 carcasses taken from healthy birds showed that adult loons accumulated higher levels of organochlorine and mercury residues than did juveniles. Tissues with high fat contents contained higher organochlorine levels while kidney, liver, and feathers had the highest mercury levels. Thirty loons were found to be emaciated with visibly lesser amounts of body fat and significantly lower levels of lipids in pectoral muscle tissue. Organochlorine but not mercury residues were one to two orders of magnitude higher in the wet tissues of emaciated birds than healthy birds. Higher residues of organochlorine chemicals were found in the uropygial gland, the oil secreted by this gland and belly and back feathers of emaciated birds when compared to healthy birds. It was concluded that losses of organochlorine chemical residues could occur through this gland. While mercury levels in feathers were elevated, mercury did not accumulate in the uropygial gland or in the secreted oil and was not the route for mercury content in feathers.

Freeman, H.C. and G.B. Sangalang. 1977. A study of the effects of methylmercury, cadmium, arsenic, selenium and a PCB (Aroclor 1254) on adrenal and testicular steroidogeneses [Abstract Only]. Arch. Environ. Contam.

An in vitro study on the effects of the contaminants polychlorinated biphenyl (Aroclor 1254), methylmercury, arsenic, cadmium, and selenium on the biosynthesis of steroid hormones in the gray seal (Halichoerus grypus) indicated altered steroid biosynthesis. Biotransformed delta 4-androstane-3, 17-dione (delta 4A), dehydroepiandrosterone, 11-ketotestosterone (11-KT), and testosterone were detected in all seal testicular incubates. Yields of 11-KT were greatly increased in the presence of Aroclor 1254. All contaminants except arsenic and selenium stimulated the in vitro biosyntheses of testosterone, with the greatest increase in production of testosterone being in the cadmium-treated tissue. Cortisol, corticosterone, aldosterone (ALDO) but no cortisone, were biosynthesized by the seal adrenal tissue. Corticosterone was the principal transformation product in all incubations with less corticosterone produced by the treated adrenals than by the control. The lowest yield of corticosterone was achieved by the selenium-treated adrenal. The yield of aldosterone was also lower in all contaminant treated incubations, with selenium and cadmium giving the greatest inhibition. More cortisol was biosynthesized by all the treated adrenals than by the control. The greatest increase of production of cortisol (6-fold) from progesterone was by the arsenic-treated adrenal.

Gilmour, C.C., E.A. Henry and R. Mitchell. 1992. Sulfate stimulation of mercury methylation in freshwater sediments. Environ. Sci. Technol., 26(11):2281-2287. (MESB 12/15/92)

Experimental additions of sulfate to either anoxic sediment slurries or lake water above intact sediment cores resulted in increased microbial production of methylmercury from added inorganic mercury. Sediment depth profiles of bacterial sulfate reduction and mercury methylation were similar, and specific inhibition of sulfate-reducing bacteria blocked methylmercury production at all depths. In situ methylmercury concentrations, like sulfate-reduction rates, were highest near sediment-water interface and in shallow sediments. These data suggest that sulfate-reducing bacteria are important mediators of mercury methylation in lacustrine sediments and provide a mechanism for increased methylmercury bioaccumulation in water bodies affected by increased sulfate deposition.

Greenberg, A., I. Wostenko, H. Chen, S. Krivanek, J.P. Butler, J. Held, P. Weiss and N.M. Reiss. 1992. Mercury in Air and Rainwater in the Vicinity of a Municipal Resource Recovery Facility in Northwestern New Jersey. Paper presented at the May 8, 1992 Air & Waste Management Association Meeting, Durham, North Carolina. 8p. (MESB 1/12/93)

Sampling of ambient air for elemental mercury as well as soluble mercury in rainwater was carried out at a number of sites in the vicinity of a municipal resource recovery facility (RRF) in northwestern New Jersey. This rural region appears to have a relatively low atmospheric mercury background. The predominant form of mercury emitted by a municipal RRF is anticipated to be mercuric chloride, thus producing higher local levels of water-soluble mercury compared to background mercury. The results of 6 rain events suggest the contribution of the RRF. Analysis of muscle and live tissue of eels do not



indicate unusual accumulation of mercury. Conclusions concerning potential health impacts await future collection of more data and the assessment of human and wildlife exposure routes.

Harada, Y. 1966. Congenital (or fetal) Minamata disease, pp 93-117. IN Katsanuma, M. (ed.). Minamata Disease, Study Group on Minamata Disease, Kumamoto Univ., Japan. (MESB 3/26/93)

Twenty-two cases of children which manifested the syndrome of severe central nervous system disturbance at the southern part of Minamata City during 1955 to 1959 were reported. The clinical features are the same with severe cerebral palsy or cerebral dysfunction syndrome. According to the facts described, it is thought that this disease is congenital Minamata disease. Minamata disease belongs to the disease of the central nervous system, being caused by intake of mercury contaminated fishes and shells of Minamata Bay.

Harrison, K.G. (ed.). 1993. Michigan Environmental Science Board Mercury Panel Meeting Minutes, Tuesday, January 26, 1993. Michigan Environmental Science Board, Lansing. 15p. (MESB Minutes 1/26/93)

Minutes contain discussions of draft papers prepared by Panel members. The papers are attached to the minutes. The topics discussed include, mercury in sediments in Michigan; bacterial action on mercury, mercury in the atmosphere, risks to human populations from mercury, mercury exposure sources and pathways, regulations governing mercury, mercury in surface water and fish, mercury in wildlife, protection from methylmercury effects, and options for controlling harmful emissions. Assignments were made by the Panel Chair to prepare the first draft response to the Governor's directives:

- Directive 1. Compile Data (Harrison, Long) and Health Risks (Fischer, Demers and Bulkley),
- Directive 2. Sources, Pathways and Exposure (Premo or Long, Wolff and Olsen),
- Directive 3. Standards and Abatement (Bulkley, Premo and Harrison),
- Directive 4. Control Options (Wolff, Cook and van Ravenswaay), and
- Directive 5. Further Studies Needed (Each subcommittee).

Harrison, K.G. (ed.) 1992a. Michigan Environmental Science Board Mercury Panel Meeting Minutes, Monday, December 14, 1992. Michigan Environmental Science Board, Lansing. 19p. (MESB Minutes 12/14/92)

Minutes include two presentations (see Porcella, 1992 and Clark, 1992) and a discussion on the ongoing Electric Power Research Institute and USEPA research projects including mercury emissions, atmospheric transport, transformation and modelling, ecological cycling and fish accumulation, and risk assessment and human health. Also included in the minutes is a presentation and discussion on a series of conclusions reached by Drs. Larry Fischer and Raymond Demers (see Fischer and Demers, 1992) regarding methylmercury exposure

relative to human health. Finally, a presentation by Mr. John Hesse (Michigan Department of Public Health) on the basis for the current Michigan Fish Consumption Advisory and a brief discussion on the levels of mercury in the sediments are contained.

Harrison, K.G. (ed.). 1992b. Michigan Environmental Science Board Mercury Panel Meeting Minutes, Friday, October 16, 1992. Michigan Environmental Science Board, Lansing. 18p. (MESB Minutes 10/16/92)

Mercury Panel comments on the Michigan Department of Natural Resources 1992 draft report on mercury (see MDNR, 1992c). Specifically, the Panel critiques the report in terms of its knowledge and understanding of the environment, environmental fate and transport of mercury, levels of mercury contamination, and mercury toxicity in wildlife and humans.

Harrison, K.G. (ed.). 1992c. Michigan Environmental Science Board Meeting Minutes, Friday, September 11, 1992. Michigan Environmental Science Board, Lansing. 5p. (MESB Minutes 9/11/92)

Document presents the minutes of the first meeting of the Michigan Environmental Science Board. Minutes address the expectations of Michigan Governor John Engler regarding the performance of the Board and the expectations of the Board Chair regarding the work generated by the Board Members. Presented as an attachment to the minutes is the Governor's first charge to the Board. The Board is asked by the Governor to review and evaluate the data available on mercury contamination to the environment and human health and to propose options for controlling or eliminating the harmful emissions. It is decided to have the entire Board serve as the Panel to address the mercury issue. Specific work assignments are made to the Panel Members by the Board Chair.

Hesse, J.L. [1992]. Input to the Board's Review of the Mercury Issue. Correspondence to the Michigan Environmental Science Board, December 16, 1992. Michigan Department of Public Health, Lansing. 17p. (MESB 1/12/93)

Correspondence discusses toxicological basis of the mercury trigger value for Michigan's fish consumption advisories. A summary of an experiment conducted by Dr. Tom Clarkson, University of Rochester, is presented in which Dr. Clarkson consumed mercury contaminated northern pike and then analyzed his blood for a period of time. The experimental results correlated well with half-life estimates of mercury in humans. Data are also presented on mercury levels in outdoor air in American cities and in particular, the Detroit metropolitan area, and on the average intake of total dietary mercury measured in the U.S. over a number of years for various groups.

Humphrey, H.E.B. 1974. Mercury Project - Update Report. Michigan Department of Public Health, Lansing. 6p. (MESB 3/26/93)

Report constitutes an update to the 1972 MDPH report on mercury (see Humphrey, et al., 1972). The update shows that persons who consumed fish from Michigan's Great Lakes had elevated levels of mercury in their blood and that a significant positive correlation between the quantity of fish eaten and the

mercury level found in blood could be demonstrated. Also, the update confirms that a person eating fish from Lake St. Clair (site of mercury contamination) would be expected to have a higher exposure to methylmercury and therefore a greater measurable body level than a person eating fish from another body of water. The threshold level for the appearance of symptoms of mercury poisoning is 200 ppb. A safe level, as suggested by the Federal Drug Administration, is considered to be 20 ppb. Approximately one half of the fish-eaters studied in Algonac had blood levels in excess of 20 ppb with the highest level, 95.6 ppb, being recorded in the highest fish consumer (126 pounds per year). While no final conclusions could be made concerning the effects of mercury contaminated fish on the health of humans who consume them, the study suggests that in all probability, the health question is not a matter of an acute toxicity or an immediately recognizable disease state but rather a question of toxic build-up within the body, which may produce a latent disease or a chronic condition over a period of time.

Humphrey, H.E.B. 1973. Mercury concentrations in humans and consumption of fish containing methylmercury [Abstract Only]. IN Proceedings: Heavy Metals in the Aquatic Environment International Conference, December 1973. Vanderbilt University, Nashville Tennessee. (MESB 3/26/93)

Certain species of fish from Lake St. Clair contain a questionably toxic concentration of mercury, over 0.5 ppm. Accordingly, the relationship between whole blood total mercury concentrations and consumption of fish has been studied in this and another area of Michigan. Randomly sampled adult residents of Algonac, Michigan who eat less than 6 lbs of fish annually from the St. Clair (noneaters) were contrasted with residents eating 26 lbs or more of such fish annually (eaters). These were compared with similarly defined noneaters and eaters in South Haven, Michigan where Lake Michigan fish contain less than 0.5 ppm of mercury. Blood mercury levels for 65 Algonac noneaters averaged 5.7 ppb and ranged from 1.1 to 20.6 ppb. Comparative values for 42 South Haven noneaters were 5.2 ppb and 1.6-11.5 ppb, respectively. Mercury levels for persons who ate fish were higher in both communities. Blood mercury levels for 42 Algonac fish eaters averaged 36.4 ppb and ranged from 3.0 to 95.6 ppb. Comparative levels for 54 eaters from South Haven were lower, averaging 11.8 ppb and ranging from 3.7 to 44.6 ppb. The data show that a direct relationship between the quantity of fish consumed and the concentration of mercury observed in human blood exists. Preliminary tests for methylmercury in the same human blood samples indicate that relationships similar to those observed for total mercury occur. Eating of sport fish from the St. Clair waters apparently leads to some absorption of methylmercury; however, at lower than known toxic levels.

Humphrey, H.E.B., M.L. Budd, H. Price and N.S. Hayner. 1972. Mercury Project, A Preliminary Report, December 1972. Michigan Department of Public Health, Lansing. 19p. (MESB 3/26/93)

In response to a mercury problem in Michigan, a field survey of mercury exposure was completed in Algonac and South Haven, Michigan. Laboratory methods for the detection of total mercury in human blood and hair specimens were developed and testing was initiated. Approximately 100 persons from each community, half of whom were randomly selected persons who ate little or no

fish and half of whom were persons who ate 26 lbs of fish or more per year, agreed to participate in the study. The available portion of laboratory data suggests that all tested participants had small but detectable amounts of total mercury in their blood and that persons who ate fish from Lake St. Clair and/or the St. Clair River had higher levels of total mercury in their blood. Further laboratory tests and compilation of questionnaire information will be continued.

Hurley, J.P., C.J. Watras and N.S. Bloom. (In press). Mercury cycling in a northern Wisconsin seepage lake; the role of particulate matter in vertical transport. 9p. (MESB 3/19/93)

During summer stratification, total mercury reached maximum concentrations in the oxygen-depleted, hypolimnion of Little Rock Lake, Wisconsin. Initially, the hypolimnetic increase was attributed solely to redox-controlled release of mercury from bottom sediments. However, subsequent depth profiles of mercury indicated that hypolimnetic mercury enrichment could also result from the downward transport and recycling of particulate mercury prior to incorporation in the sediments. Contrasts between iron and mercury cycles in the lake reinforce this notion. Increases in hypolimnetic iron were observed during both summer and winter oxygen decreases. In contrast, hypolimnetic mercury concentrations declined during winter. In the ice-free season, the distribution of particulate mercury correlated with the distribution of chlorophyllous particulates in the lake, re-emphasizing the importance of biotic processes in controlling cycling in the hypolimnion.

Iverfeldt, A. and O. Lindqvist. 1986. Atmospheric oxidation of elemental mercury by ozone in the aqueous phase, Atmos. Environ., 20:1567-1573. (MESB 3/24/93)

The aqueous phase oxidation of elemental mercury by ozone has been investigated in the laboratory using a quartz glass reactor with gas phase concentrations of 400-1,800 ng/m<sup>3</sup> and 70-200 ppb for mercury-zero and ozone, respectively. The absorption of mercury in the water phase was increased by three orders of magnitude with ozone present. If the oxidation were to proceed with the same speed in liquid water in contact with the atmosphere conversion rates of 1-4%/h would be implied. Experiments using ambient urban air with 2-6 ng mercury/m<sup>3</sup> confirm the process at elevated ozone concentrations. At ambient ozone concentrations competitive reactions become important; e.g., ozone consumption by sulfur dioxide, hydrocarbons, etc., and even some reduction of mercury-two could occur. The atmospheric oxidation of mercury-zero by ozone in water is thus considered important at high ozone levels in regionally polluted or remote areas.

Jarabek, A.M. [1993]. [USEPA review comments on Volume II, Environmental and Health Issues, Task Force on Mercury Emissions Standards Setting Preliminary Report]. Correspondence to Dr. Alan Stern, New Jersey Department of Environmental Protection and Energy, January 18, 1993. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. 5p. (MESB 2/24/93)

Three USEPA reviewers critiqued portions of Volume II, Environmental and Health Issues, of the 1992 New Jersey draft report on mercury (see NJDEPE, 1992b). The reviewers expressed concern regarding the report's, (1) use of a inhalation reference concentration (RFC) with respect to mercury speciation (it may have been used inappropriately inconjunction with other forms of mercury other than elemental); (2) its focus on municipal solid waste incinerators over other forms of anthropogenic mercury emission emitters, most notably, coal-burning facilities; (3) its assumption that all municipal solid waste incinerator emissions are mercuric chloride vapor; (4) its calculated mean of 3.5 µg/day methylmercury intake from fish for the total population; and (5) its use of an oral reference dose, and its suggested use of 10 µg/g as a LOAEL.

Jensen, S. and A. Jernelov. 1969. Biological methylation of mercury in aquatic organisms. Nature (London), 223:753-754. (MESB 3/15/93)

Paper reports that both mono and dimethylmercury can be produced in bottom sediments and in rotten fish. The biological methylation of mercury compounds provides an explanation for the fact that methylmercury is found in fish, even if all known sources of mercury in the environment are in the form of inorganic mercury or phenyl mercury. The formation of the volatile dimethylmercury may be a factor in the redistribution of mercury from aqueous industrial wastes.

Johansson, K., M. Aastrup, A. Andersson, L. Bringmark and A. Iverfeldt. 1991. Mercury in Swedish forest soils and waters - assessment of critical load. Water, Air and Soil Pollution, 56:267-281. (MESB 3/19/93)

In the paper, the occurrence and fluxes of mercury in Swedish forest soils and waters are reviewed and synthesized. The main objective is to describe and evaluate the present transport of anthropogenic mercury from atmospheric deposition, through the terrestrial compartment and running waters to lake basins and also to comprehend the main factors influencing these fluxes. The transportation and distribution of mercury in forest soils and waters is closely related to the flow of organic matter. The content of mercury in humic matter is higher in southern and central areas compared to the north of the country. Compared to background concentrations, the mercury content has increased in the southern and central part by about a factor of 4-7, while the overall increase in the north is by about a factor of 2 to 8. The increased content of mercury in forest soils may have an effect on organisms and biological processes in the soil.

Johansson, K. and A. Iverfeldt. 1992. The impact of increased mercury in soil on the transport of mercury to lakes in Sweden. IN International Conference on Mercury as a Global Pollutant, May 31 - June 4, 1992 [Abstracts Only]. Electric Power Research Institute, U.S. Environmental Protection Agency, Vattenfall and Environmental Canada: AES, Monterey, California. 133p. (MESB 10/21/92)

The increased atmospheric deposition of mercury this century has caused an accumulation of mercury in forest soils in Sweden. In southern Sweden and in central Sweden along the Bothnian coast in particular, concentrations in the

mor layer of the soils are markedly high. Approximately 80% of the mercury content in the mor layer is of anthropogenic origin. Despite the fact that emissions have been drastically reduced in the last decades, the accumulation of mercury in soils is still continuing and, accordingly, concentrations of mercury are increasing. A reduction of about 80% of the deposition has to be achieved to reach a balanced input/output budget for the soils in Scandinavia. The overall aim of the study is to assess the impact of the increased content of mercury in forest soils on the load on inland waters.

An initial evaluation indicates that there is a strong, but varying site-specific relationship between mercury and humic matter in the run-off waters from catchments in southern and central Sweden. The variation between the areas is probably not due to differences in the concentrations of mercury in soils, but mainly dependent on the character of the catchments. Lower values for mercury in the humic matter are predominantly found in run-off waters from areas with large expanses of peatland and where there are lake basins. This pattern might be caused by a separation of different forms of humic matter in the transport processes from soils to waters, where larger, more contaminated humic fractions from the top soil layers are retained in peatland and lake basins.

There is also a close correlation between the content of mercury and humic matter in the run-off waters from catchments in northern Sweden, but the ratio of these compounds is comparatively low and shows no major variation. The generally low content of mercury in the humic matter is probably due to the lower content of mercury in soils. The concentration of mercury in humic matter is about the same in run-off waters, soils and also in the top layers of sediments from lakes in this part of the country.

Jones, K.H. [1993a]. A Review of the Preliminary Report: Volume 2, Environmental and Health Issues by the Task Force on Mercury Emissions Standard Setting of the New Jersey Department of Environmental Protection and Energy (September 1992), January 1993. Zephyr Consulting, Seattle, Washington. 20p. (MESB 1/12/93)

Paper reviews and compares the methodologies of 2 interpretations used by the NJDEPE to determine an Acceptable Daily Intake (ADI) value of 0.07 µg/kg/day in light of the methodologies used by the Michigan Environmental Science Board (MESB) to determine an ADI value of 0.7 µg/kg/day. Jones concludes that it would be more prudent to stay with the current USEPA IRIS ADI of 0.3 µg/kg/day for assessment purposes and to use the 0.07 µg/kg/day ADI value as a "what if" target assuming that the NJDEPE can answer the opposing comments raised by the MESB. The paper further comments on the NJDEPE data evaluation of wet deposition estimates, dry deposition and water column sedimentation and bioaccumulation factors.

Jones, K.H. [1993b]. Comparisons of Wet Deposition Measurements Versus Modeled Estimates, Warren Co. WTE, January 1993. Zephyr Consulting, Seattle, Washington. 8p. (MESB 1/12/93)

Paper uses data from Greenberg et al. (1992) to compare the measure wet deposition to model air and rainwater mercury concentration estimates which

have been made for other existing and proposed New Jersey waste-to-energy facilities. The reasonable agreement between the measured deposition and rough modeling results indicate two possible conclusions; the outcome is fortuitous or wet deposition modeling is reasonably representative of actual conditions.

Jones, K.H. [1993c]. Environmental Mercury Impacts from a Municipal Incineration Perspective, January 1993. Zephyr Consulting, Seattle, Washington. 8p. (MESB 1/12/93)

Jones summarizes the 1992 Monterey Conference on Mercury as a Global Pollutant and discusses the role of anthropogenic sources of mercury, including municipal solid waste incinerators with respects to observed environmental impacts; the sources of human exposure to environmental mercury; and the ways that the conference research information may be used to better assess the potential environmental impacts of municipal solid waste incinerator emissions in risk assessments.

Jones, K.H. [1992]. Review of MDNR Mercury Impact Analysis of the Proposed Oakland WTE on Lower Trout Lake, December 10, 1992. Zephyr Consulting, Seattle Washington. 7p. (MESB 1/12/93)

Jones states that the Michigan Department of Natural Resources' (MDNR) reanalysis of the potential total mercury impacts of the proposed Oakland County waste to energy facility on Lower Trout Lake is deficient in technical areas and does not justify the conclusions reached. The analysis is flawed because of the misapplication of the various research results cited as well as outdated information. The MDNR analysis should not be used as a basis for siting restrictions for waste to energy facilities as proposed in Michigan Senate Bill 795 (see Dunakiss, 1992). Jones finds Michigan Rule 57 water quality standard and its derivation outdated in terms of current knowledge about the speciation of mercury in water bodies. The current standard of 1.3 ng/l total mercury should be minimally modified, he says, to specify it as a monomethylmercury limitation. If this appropriate adjustment were made, even the MDNR estimate of the total mercury burden of the proposed Oakland County waste-to-energy facility on Lower Trout Lake would more than likely be insignificant. More appropriate wet deposition estimates show an insignificant methylmercury contribution by the waste to energy facility to Lower Trout Lake.

KBN Engineering & Applied Sciences, Inc. 1992. Mercury Emissions to the Atmosphere in Florida: Final Report, August 1992. Florida Dept. of Environmental Regulations, Tallahassee. 266p. (MESB 11/16/92)

Mercury emissions from both anthropogenic and natural sources are estimated. The anthropogenic sources considered included municipal solid waste combustion, electric utility industry, medical waste incineration, sugar cane industry, pulp and paper industry, cement industry, other fossil fuel combustion sources, paint manufacturing and application, electrical apparatus, dental preparation usage, laboratory usage, transportation fuel burning, open burning, miscellaneous sources and byproduct disposal areas. Natural sources considered included soil degassing and forest/natural fires. For the years

1981 and 1990, the average mercury emissions in Florida's atmosphere were estimated to be 62,692 lbs and 62,888 lbs, respectively. Anthropogenic sources were estimated to emit 38,173 lbs and 38,369 lbs, respectively, for the same period. Natural sources were estimated to emit 24,519 lb/yr in each year.

Anthropogenic sources were estimated to be about 60% of total estimated mercury emissions. Those sources which accounted for more than 5% of total emissions in 1990 were resources recovery facilities (14.6%), the electric utility industry (10.7%), medical waste incinerators (14.0%), paint application (11.1%) and electrical apparatus (5.9%). The other anthropogenic sources were each estimated to emit less than 2% of the total 1990 estimated mercury emissions. The natural mercury sources were estimated to emit about 40% of total estimated mercury emissions, with the majority being from soil degassing.

Keeler, G.J. [1993]. Personal communication to George Wolff, Michigan Environmental Science Board. School of Public Health, University of Michigan, 109 Observatory St., Ann Arbor, Michigan. (MESB 3/26/93)

This was actually a series of conversations beginning with a visit to Dr. Keeler's laboratory on September 23, 1992, and phone conversations were to observe his state-of-the-art ultra-clean mercury analytical laboratory, discuss the data presented in Hoyer et al. (In press) and Lamborg et al. (In press), and view his most recent, unpublished data. The unpublished data include the gaseous mercury data from Ann Arbor and Detroit that appear in Table 1 of the MESB Mercury Panel Report, and the precipitation data from Ann Arbor, Pellston and South Haven that appear in the discussion on Directive 2. Other data that he presented include: data showing the presence of an unreactive organic form of mercury in the particulate phase; a source-receptor analysis of the high concentrations observed in Detroit; seasonal variations of mercury in precipitation at Pellston (higher in summer); and data suggesting that coke ovens might be a significant source of mercury. He also mentioned that he felt he could obtain in-plume samples using a tethered balloon carrying a small sampler.

Kjellstrom, T., P. Kennedy, S. Wallis, A. Stewart, L. Friberg, B. Lind, P. Wutherspoon, and C. Mantell. 1989. Physical and Mental Development of Children with Prenatal Exposure to Mercury from Fish, Stage 2: Interviews and Psychological Tests at Age 6. National Swedish Environ. Protection Board Report No. 3642, Solna, Sweden. 112p. (MESB 3/26/93)

A follow-up study of the developmental and psychological effects of prenatal exposure to methylmercury via fish was carried out in a group of New Zealand children whose mothers had a high fish consumption during pregnancy. Preliminary studies had shown that fish with elevated mercury levels were sold in Auckland shops and people with a high fish consumption could reach intakes of mercury 3-4 times the WHO/FAO provisional tolerable weekly intake.

Hair samples and diet questionnaire were received from 11,000 new mothers in maternity hospitals in the northern part of the New Zealand North Island. About 1,000 of these mothers had consumed fish more than 3 times per week



during the pregnancy. Their hair samples were analyzed and 73 mothers had average hair mercury levels during their 9-month pregnancy above 6 mg mercury/kg. Their 74 children (one pair of twins) was identified as the high exposure group. The highest hair mercury was 86 mg mercury/kg.

A second stage follow-up at age 6 was carried out in order to confirm or refute the findings at age 4. This time, the high exposure children were compared with 3 "control" groups with lower prenatal mercury exposure. The mothers of 2 of these groups had high fish consumption and average hair mercury during pregnancy at 3-6 mg/kg and 0-3 mg/kg, respectively. The third group of mothers had lower fish consumption and hair mercury 0-3 mg/kg. The 3 control groups and the high exposure group were matched for maternal ethnic group, age, smoking habits, place of residence and duration of living in New Zealand as well as for child's sex.

At age 6, a total of 61 of the 74 high exposure children could be studied. Each child was tested with a "battery" of scholastic, psychological and behavioral tests. The maternal hair mercury during the pregnancy was measured on stored hair samples in those cases where analysis results were not already available. In as many of the children as possible lead analysis was made of umbilical cord blood and garden soil at the child's residence. In all the analyses quality assurance procedures were incorporated.

The main findings were that the "normal" results of the psychological test variables were influenced by the child's ethnic background and social class, that there is an apparent consistent association between high prenatal methylmercury exposure and decreased performance in the tests, that the methylmercury exposure contributes only a small part of the variations in test results and that an average hair mercury level during pregnancy of 13-15 mg/kg was associated with the decreased test performance. The equivalent monthly peak hair mercury level was about 25 mg/kg. Decreased performance of the psychological tests may have occurred at even lower exposure levels, but the study group was not large enough to ascertain this. Other epidemiological studies and animal experiments have shown that prenatal methylmercury exposure can cause central nervous system effects.

Lathrop, R.C., P.W. Rasmussen and D.R. Knauer. 1991. Mercury concentrations in walleyes from Wisconsin (USA) lakes. Water, Air and Soil Pollution, 56:295-307. (MESB 3/24/93)

Descriptive statistics were developed for mercury concentration data for 1,103 walleyes (Stizostedion vitreum vitreum Mitchill) from 219 Wisconsin lakes of various neutralizing capacity (ANC). Lake means of mercury concentrations in skin-on fillets of walleyes for various fish total length groups and lake ANC intervals increased as fish length increased and as lake ANC decreased. Lake mean concentrations exceeded the Wisconsin Division of Health standard of 0.5 µg mercury/g for walleyes  $\geq 40.0$  cm in lakes with ANC  $\leq 300$  µeq/l, and were similar to the standard for fish 55.0 to 64.9 cm from lakes with ANC  $\geq 900$  µeq/l. A linear regression model predicting walleye mercury from fish length and lake ANC was developed, but only 42% of the variation in mercury concentration was explained by the model. Individual lake relationships of walleye mercury concentrations to fish length differed greatly among lakes of

similar ANC. A comparison of walleye mercury concentrations in lakes with ANC <300  $\mu\text{eq/l}$  in northeastern Minnesota, northern Wisconsin, and southeastern Ontario indicated that concentrations increase from west to east.

Lee, G.F. and R.A. Jones. 1992. Municipal Solid Waste Management in Lined, "Dry Tomb" Landfills: A Technologically Flawed Approach for Protection of Groundwater Quality. G. Fred Lee & Associates, El Macero, California. 68p. (MESB 2/2/92)

The review presents a discussion of many of the technical issues pertaining to the ability of "dry tomb" type landfills to provide for groundwater quality protection for as long as the buried wastes represent a threat to groundwater quality.

Leonard, D. [1992]. Comments on Draft MDNR Report on Mercury in Michigan's Environment--Causes and Extent of the Problem. Correspondence to the Michigan Department of Natural Resources, September 16, 1992. Detroit Edison, Detroit. 5p. (MESB 9/23/92)

Correspondence comments on four aspects of the Michigan Department of Natural Resources draft 1992 report on mercury (see MDNR 1992c). The four areas of concern include, the relationship between atmospheric mercury loadings and mercury levels in fish, the appropriateness of the Michigan Department of Public Health's (MDPH) fish advisory and the manner in which the MDPH statistically analyzes data, the threat of mercury to the public, and the mercury content in coals. In three of the four areas of concern, Leonard suggests that the summary statement inexplicably ignores the contravening views. In the fourth instance, the contravening view is not expressed.

Lindberg, S.E., T.P. Meyers, G.E. Taylor, R.R. Turner and W.H. Schroeder. 1992. Atmosphere-surface exchange of mercury in a forest: results of modeling and gradient approaches. J. Geophys. Res., 97:2519-2528. (MESB 3/24/93)

Previously published dry deposition models were modified to estimate deposition velocities ( $V_d$ ) for mercury in both fine aerosol and vapor form to forest canopy surfaces. Aerosol and total vapor phase mercury concentrations in air previously measured at Walker Branch Watershed in Tennessee have been used with model results to estimate dry deposition to a deciduous forest. The concentration data confirm that airborne mercury is dominated by vapor forms at the site and exhibits concentrations moderately above continental background levels. The modeled  $V_d$  values reflect published data which suggest that dry deposition of mercury vapor is strongly controlled by surface transport processes, notably stomatal and mesophyll resistances, the latter dominating. Weekly mean  $V_d$  values ranged from 0.006 (winter) to 0.12 (summer cm/s). Concentration gradients of mercury vapor in air were also measured above the forest to estimate air-surface exchange during short-term experiments. While the model results indicate that the canopy is a sink for mercury vapor, the concentration profiles suggest that the forest soils are a source during some periods, the combined effect of which is net mercury fluxes in the upward direction. Application of a detailed canopy turbulence model yielded soil emission rates of the order of 50 ng mercury/m<sup>2</sup>/h, approximately 10% of which is deposited in the canopy. The modeled dry

deposition estimates plus limited measurements of wet deposition in this area suggest that dry and wet deposition may be comparable in magnitude.

Lindberg, S.E., R.R. Turner, T.P. Meyers, G.E. Taylor and W.H. Schroeder. 1991. Atmospheric concentrations and depositions of Hg to a deciduous forest at Walker Branch watershed, Tennessee. Water, Air and Soil Pollution, 56:577-594. (MESB 3/24/93)

Aerosol and total vapor phase mercury concentrations in air have been measured at Walker Branch Watershed, Tennessee for approximately 2 yrs. Airborne mercury at this site is dominated by vapor forms which exhibit a strong seasonal cycle, with summer maxima that correspond to elevated air temperature. Concentrations at a site within 3 km are significantly elevated due to emissions from mercury-contaminated soils. The concentration data have been combined with a recently modified dry deposition model to estimate dry deposition fluxes to the deciduous forest at Walker Branch. Weekly mean modeled  $V_d$  values for mercury-zero ranged from  $<0.01$  (winter) to  $> 0.1$  (summer) cm/s. Weekly dry deposition fluxes ranged from  $<0.1 \mu\text{g}/\text{m}^2$  during winter to  $1.0 \mu\text{g}/\text{m}^2$  in the summer. The dry deposition estimates plus limited measurements of wet deposition in this area indicate that dry deposition may be the dominant input process in this forest, at least during the summer.

Lodenius, M. 1992. Mercury in terrestrial ecosystems: a review. IN International Conference on Mercury as a Global Pollutant, May 31 - June 4, 1992 [Abstracts Only]. Electric Power Research Institute, U.S. Environmental Protection Agency, Vattenfall and Environmental Canada: AES, Monterey, California. 133p. (MESB 10/21/92)

The occurrence and spreading of mercury in the biosphere is different from that of most other metals. Due to the high volatility of elemental mercury this metal is spread very effectively. Knowledge of the occurrence and accumulation mechanisms of mercury in terrestrial ecosystems is sparse. In the soil mercury is strongly bound to organic matter and fine particles. The importance of humic matter for the sorption of mercury is well documented. This binding is almost unaffected by fluctuations in pH and chlorine concentration. The humic matter is the main carrier in the transport of mercury from terrestrial to aquatic ecosystems. Mercury is strongly bound to organic matter even at low pH values. Mercury in soil solution may be phytotoxic even in small concentrations. Toxic effects on tree roots are mainly determined by the amount of soluble metal ions. A strong uptake of mercury has been found from earthworms and other soil organisms but there seem to be also an effective excretion which prevents any further biological accumulation.

Terrestrial plants normally contain only small amounts of mercury. The uptake of this metal from the soils is poor and only small amounts of organic mercury compounds have been detected. Mercury may be readily absorbed through the leaves directly from the air but there is also a re-emission, which reduces the concentrations in leaves. Mosses and lichens accumulate mercury from the air due to their exceptional leaf structure.

The uptake of metals in macrofungi is in many respects different from that of plants. The strong accumulation of mercury in certain species is one example of these differences. The mechanism of metal uptake in fungi and mycorrhiza is poorly known. Low concentrations of mercury are found from most fungi: in most cases less than 5 µg/g (dry weight). The mean concentration of lawn decomposer species is clearly higher than that of mycorrhizal fungi or wood decomposer fungi. Small amounts of methylmercury have been detected in fungi. The use of organic mercury compounds in agriculture caused an intoxication of terrestrial food chains in the 1950's and 1960's until the use of these compounds was banned. The agricultural use of mercury can be seen in the mercury concentrations of feathers of the Sparrowhawk (Accipiter nisus); the highest concentrations being in feathers collected in the 1960's.

The mercury concentrations of terrestrial mammals are usually low; often considerably lower than in corresponding species representing aquatic food chains. The concentrations are low in muscle, fat and liver and slightly higher in the kidney. In Finnish reindeer the mercury concentrations are very low (approximately 0.01 µg/g in muscle) even if the food contains moderate amounts of this metal.

Long, D.T. [1993]. Preliminary Report on Mercury in Sediments of Michigan for Mercury Panel of the Michigan Environmental Sciences Board, January 26, 1993. Michigan Environmental Science Board, Lansing. 14p. (MESB 1/27/93)

Paper reviews and summarizes mercury sediment data compiled from a Michigan Department of Natural Resources and an ongoing Michigan State University investigations. Background mercury in lake sediments ranged from 18 ng/g to 110 ng/g (ppb) and averaged 55 ng/g. Background concentrations for inland lakes in Michigan had a greater range of values and a higher average than values in the sediments of the Great Lakes. However, the average of 55 ng/g for the inland lakes did not appear to be significantly different from that of soils from around the country. The causes of the difference between background values in the sediments of the Great Lakes and inland lakes of Michigan is not known. In all lakes except one, mercury was enriched in the surface sediments compared to background concentrations. Enrichment factors (surface concentration/background concentration) ranged from 0.8 to 6.7.

There appeared to be a regional pattern of enrichment of mercury in the sediments. Of the inland lakes studied, 13 showed concentrations of mercury in the sediments to be increasing, 3 showed concentrations to decreasing and 7 showed no recent changes in concentrations. In all cases except one, changes in mercury concentrations changes followed observed changes in lead concentrations. The cause of the increasing lead and mercury concentrations in sediments of inland lakes is unclear.

Long, D.T. [1992]. Review of Mercury in Michigan's Environment, October 16, 1992. Michigan Environmental Science Board, Lansing. 10p. (MESB Minutes 10/16/92)

Paper reviews and summarizes what is currently known about natural and anthropogenic sources of mercury in Michigan. Long presents data on mercury concentrations in selected basins of Lake Superior and on mercury and lead

concentrations in sediments in Lake Superior from various researchers. He concludes that (1) the biogeochemical cycle of mercury is complex and many details including pathways to humans have not been worked out yet; (2) concentrations of mercury in many environments are not well known; (3) natural emissions of mercury are significant; (4) the atmosphere plays a major role in adding mercury; (5) mercury is a regional and perhaps global problem, not limited to Michigan; (6) mercury is being added to the terrestrial as well as aquatic environments, but the terrestrial-aquatic linkages are not well defined; and (7) there will probably be a lag time for the environment to clean itself once mercury pollution has stopped. Long thinks that there are two levels of the mercury problem in Michigan. The first is the regional, or transboundary, problem. The second is the local problems such as Deer Lake and the high concentrations of mercury in fish in some lakes around Detroit.

LSB. 1992. Mercury: Master of Illusion, Environmental Puzzle, June 1992. Science and Technology Division, Legislative Service Bureau, Lansing, Michigan. 43p. (MESB 9/23/92)

Report constitutes a review of some of the available literature on mercury. Topics reviewed include, mercury and its mobility in the environment, sampling and monitoring mercury; mercury toxicity and safe levels of exposure in humans; mercury levels in water systems and fish; the state's current fish consumption advisory; natural and man-made sources of mercury; and controls of man-made source of mercury and mercury emissions.

Marsh, D.O., T.W. Clarkson, C. Cox, G.J. Myers, L. Amin-Zaki and S. Al-Tikriti. 1987. Fetal methylmercury poisoning. Arch. Neurol., 44:1017-1022. (MESB 3/26/93)

Pregnant women consumed bread that was prepared from methylmercury treated wheat. Single strands of maternal head hair were analyzed by x-ray fluorescence spectrometry. The index of fetal exposure was the maximum hair mercury concentration during gestation. Effects were measured by the frequency of psychomotor retardation, seizures, and neurological signs in the children. A dose-response relationship was demonstrated for fetal effects of methylmercury. Analysis of single hair strands provides a better index of acute or subacute fetal exposure than analysis of bundles of hair; the duration and degree of exposure are more accurately defined. A sex difference in response is also discussed.

McKeown-Eyseen, G.E., J. Ruedy and A. Neims. 1983. Methyl mercury exposure in northern Quebec. II. Neurologic findings in children. Am. J. Epidemiol., 118:470-479. (MESB 3/19/93)

The relationship between prenatal exposure to methylmercury and neurologic and developmental abnormalities was ascertained among 234 Cree Indian children aged 12 to 30 months from 4 northern Quebec communities. A pediatric neurologist, "blinded" to the children's level of exposure, assessed neurologic, physical, mental, and psychosocial development. Methylmercury exposure was estimated from maternal hair segments representing the period of pregnancy. Abnormality of the tendon reflexes, observed in 13 boys (11%) and in 14 girls (12%), was positively associated with methylmercury exposure only

in boys and there was no consistent dose-response relationship. Other neurologic disorders were less prevalent and none was positively associated with exposure; indeed, incoordination was negatively associated with exposure in girls. The mild, isolated neurologic abnormalities found after prenatal exposure to methylmercury in northern Quebec were different from the effects of prenatal exposure described in other areas, and their clinical importance can be determined only by continued medical surveillance.

MDA. 1992. MDA Officials Warn Residents to Limit Consumption of Shark Meat, Press Release, February 4, 1992. Michigan Department of Agriculture, Lansing. 1p. (MESB 4/8/93)

After laboratory tests on shark meat showed excessive levels of methylmercury, Michigan Department of Agriculture (MDA) officials warned consumers to limit their consumption of the fish.

MDA Director Bill Schuette indicated in the press release that consumers should not eat shark more than once a month, and he advised against any consumption by pregnant women, women planning to have children within a year, nursing mothers, and children under the age of 6. Schuette said 5 samples of shark were taken by agriculture inspectors from Michigan wholesale and retail food businesses. All analyses exceeded acceptable levels for methylmercury as outlined by state and federal guidelines, which is one part methylmercury per million (ppm). Methylmercury in the samples ranged from 1.0 ppm to 2.63 ppm.

Methylmercury is found in shark because they are deep ocean predators on the top of the food chain, and mercury is reported to be found in oceans throughout the world. The chemical can cause adverse health effects on humans when they are exposed to elevated levels of it on a regular basis or over a long period of time. Significant exposure can be especially dangerous for fetuses, infants and small children because methylmercury can affect fetal development and damage the central nervous system.

MDNR. 1992a. Mercury and Other Metals in Bald Eagle Feathers and Other Tissues from Michigan, Nearby Areas of Minnesota, Wisconsin, Ohio, Ontario and Alaska, 1985-1989. Michigan Department of Natural Resources, Lansing. 6p. (MESB 1/27/93)

Mercury in adult bald eagle feathers from the Great Lakes area was markedly elevated with a mean of 21.0 mg/kg in 416 feathers. Eaglet feathers had a mean concentration of 9.3 mg/kg in 163 feathers. Adult bald eagle nesting territory mean feather mercury concentrations differed significantly among the Great Lakes subregions. The Lake Superior subregion had the highest nesting territory mean feather mercury concentration at 28.3 mg/kg. The Upper Peninsula/Wisconsin, Lake Michigan/Lake Huron and the Lower Peninsula subregions were not significantly different. The Lake Erie subregion was significantly less than the other Great Lakes subregions. In terms of eaglet nesting territory mean feather concentrations, northeastern Minnesota had the highest and Lake Erie subregion had the lowest. The remaining subregions were in between and not significantly different from each other. Feathers from adult bald eagles fed artificial diets in zoos had less than 0.1 mg/kg of

mercury while eagles at Patuxent fed estuarine fish and chicken had a mean mercury feather concentration of 1.2 mg/kg. Feathers from adult bald eagles kept at the Kellogg Bird Sanctuary had a mean mercury concentration of 3.1 mg/kg. Selenium concentrations were found to be lower in adult eagles and eaglets (11.3 mg/kg and 5.4 mg/kg, respectively). A correlation coefficient for mercury/selenium in adult eagle feathers was 0.54, but was not significant for eaglets at -0.12. Although somewhat elevated, mercury concentrations in soft tissues of eagles were not found to be at toxic concentrations.

MDNR. 1992b. Michigan Fish Contaminant Monitoring Program 1992 Annual Report [pages i-vii and 1-6]. Report #MI/DNR/SQA-92-..., Michigan Department of Natural Resources, Lansing. (MESB 1/15/93)

Provides information on average mercury concentrations in fish and briefly discusses temporal trends. One fish sampled for mercury exceeded the Michigan Department of Public Health's trigger level. Contaminant data for standard edible fillet exceeded Michigan Water Quality Standards for mercury at 3 locations. Carp from the Kalamazoo River had significantly higher levels of mercury than carp from the Grand, Muskegon and Raisin Rivers and from Lake St Clair, Lake Erie-Brest Bay, Detroit River and Lake Huron-Saginaw Bay. Statistically significant spatial differences for mercury in carp from 4 Great Lakes locations were found. Walleye data for 6 Great Lakes locations showed statistically significant spatial differences in concentrations of mercury.

MDNR. 1992c. Mercury in Michigan's Environment, Causes and Extent of the Problem, June 24, 1992 Draft. Michigan Department of Natural Resources, Lansing. 178p. (MESB 9/23/92)

The report reviews and summarizes the literature on the problem of mercury contamination. Emphasis, where possible, is focused on Michigan data. The report includes information on mercury source identification and estimates of releases, environmental fate and transport of mercury, levels and significance of mercury in environmental media, mercury toxicity to aquatic and terrestrial wildlife and humans, and governmental activities related to the management of mercury in the environment. Some of the findings and conclusions reached in the report include, (1) anthropogenic sources of mercury emissions in Michigan were estimated to be greater than natural emissions in 1989 (19 tons vs 12 tons); (2) assessments of anthropogenic versus natural emissions on a national and global scale provided a similar estimate; (3) while some mercury released from anthropogenic sources is in the elemental form, a significant portion is found in the divalent form which will undergo short-range transport and be deposited in close proximity to the source; (4) background atmosphere levels of mercury are generally not high enough to result in adverse health effects from inhalation; (5) ambient mercury levels for most Michigan surface water are predicted to range from about 1 ng/l to 7 ng/l. These estimated ambient levels are approximately equal to, or just above, criteria which have been developed to protect health and terrestrial life; (6) the sediment record is believed to be an indicator of the temporal trend of increased mercury loadings to inland lakes since pre-colonial times. An apparent 3-fold sediment enrichment factor between surficial and deep sediment layers may be attributable to increased atmospheric sources of mercury or to watershed disturbances; (7) sediment mercury levels often exceed the available criteria and

guidelines developed to protect sensitive aquatic species which inhabit the sediments; (8) generally, fish residue levels of mercury in Michigan are just below or equal to mammalian and avian dietary levels which are considered potentially toxic based on laboratory studies; (9) residue mercury levels in most avian and mammalian species surveyed in Michigan are below levels known to be toxic; (10) Michigan-specific field studies of mercury effects on wildlife populations are practically non-existent; (11) there appears to be a very narrow margin of safety between background and toxic exposure levels associated with human fetal toxicity; (12) the current Michigan sport-caught fish consumption advisories and trigger level for advisories are appropriate and justifiable considering the toxicity of methylmercury to humans, the methylmercury levels in fish and the levels in human tissues associated with toxic effects.

MDNR. 1991. Michigan Fish Contaminant Monitoring Program, 1991 Annual Report [pages i-vi and 70-81]. Report #MI/DNR/SWA-91/273, Michigan Department of Natural Resources, Lansing. (MESB 1/15/93)

Provides information on average mercury concentrations in fish and briefly discusses temporal trends. The tables and discussion point out that Michigan fish average below 0.5 ppm and that the Michigan data have not discerned a temporal increase in mercury levels.

MDPH. [1992]. Summary of Mercury in Fish from Inland Lakes through 1991 [Table Only]. Michigan Department of Public Health, Lansing. 11p. (MESB 12-14-92)

Summary table presents mercury contaminated fish data for 3 groups of lakes. Group 1 lakes are those with test samples exceeding 0.5 ppm mercury. Group 2 lakes had at least one sample exceeding 0.5 ppm mercury and none exceeding 1.5 ppm mercury. Group 3 lakes had at least one sample equalling or exceeding 1.5 ppm mercury. Sampled lakes are listed individually by group, with the county where it is located, the date of the sample, the species and number sampled, the size range of the sample, and the average and maximum ppm mercury. The data are summarized by Lower and Upper Peninsula location and group.

Mierle, G. 1990. Aqueous inputs of mercury to Precambrian Shield lakes in Ontario, Environmental Toxicology and Chemistry, 9:843-851. (MESB 3/19/93)

The concentration of mercury in precipitation and in streams of a central Ontario lake were measured over a one year period. The concentrations in streams were generally very low (<5 ng/l), but during warm periods with low discharge, concentrations often exceeded 20 ng/l in a headwater stream draining a wetland. The concentration in precipitation varied from about 2 to nearly 30 ng/l and exhibited no seasonal pattern. By combining the concentration data with discharge and precipitation depth, the inputs of mercury from run-off and direct deposition were estimated. Direct wet deposition accounted for over half of the supply of mercury to the lake. The watersheds retained most of the mercury deposited. The presence of wetlands appeared to decrease retention efficiency.



Mohamed, M.K., T.M. Burbacher and N.K. Mottet. 1987. Effects of methylmercury on testicular functions in Macaca fascicularis monkeys [Abstract Only]. Pharmacol. Toxicol., 60(1):29-36. (MESB 2/19/93)

These studies were performed to investigate the effects of methylmercury on testicular function in Macaca fascicularis monkeys. In an in vitro study involving oral treatment of adult males Macaca fascicularis monkeys with methylmercury for 20 weeks, changes in spermatozoal production, motility and morphology and in serum testosterone were followed before, during and after treatment. Methylmercury treatment significantly decreased percent motile spermatozoa and scores for sperm speed and forward progression and increased percent abnormal sperm tailforms, at sub-neurotoxic levels. The methylmercury-induced increase in semen abnormalities was not accompanied by any significant changes in serum levels of testosterone. No consistent histological abnormalities were detected in testicular biopsies from the treated animals at the end of the treatment period. A good recovery pattern was observed for the methylmercury effects on sperm motility while this was unclear for the effects on sperm morphology.

Montague, P. [1991?]. Why Incinerator Ash Will Inevitably Leach Toxic Metals into the Local Environment. Environmental Research Foundation, Annapolis, Maryland. 5p. (MESB 2/2/93)

Montague critiques one investigation (see NUS Corporation, 1990) and one claim (see Forrester and Goodwin, 1989) that conclude that municipal solid waste incinerator ash does not leach metals or organics. Based on a review of the literature, Montague concludes that over time and an inevitable change in pH, the metals will eventually leach out of the ash.

Moore, E. 1993. Report on the Management of Mercury-Containing Lamps (Fluorescent and High-intensity Discharge Lamps), January, 1993. Minnesota Office of Waste Management, St. Paul. 81p. (MESB 2/3/93)

Report presents recommendations to the Minnesota Legislature about the management of spent mercury-containing lamps. Recommendations proposed include source reduction as the first and best approach to managing mercury in lamp waste. Other method discussed include separate collection and management, recycling and reclamation of mercury in lamps and system finance for business lamps.

Moser, H.D. and A.F. Voight. 1957. Dismutation of the mercurous dimer in dilute solutions. J. Am. Chem. Soc., 79:1837-1839. (MESB 3/24/93)

The dismutation of the mercurous dimer into mercuric ions and dissolved free mercury has been studied in highly dilute mercurous nitrate solutions. Radioactive tracer techniques have been used to permit measurements in the  $10^{-7}$  M range. Use is made of the extraction of free mercury into non-polar organic solvents to measure the extent of dismutation. The solutions was found to be  $(3.0 \pm 0.1) \times 10^{-7}$  M at 25°.

Nebel, K.L., D.M. White, C.R. Parrish, T.G. Zirkei, M.A. Palazzolo and M.S. Hartman. 1992. OMSS Field Test on Carbon Injection for Mercury Control,

September 1992. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. USEPA 600/R92-192. 150p. (MESB 10/22/92)

The report discusses results of a parametric evaluation of powdered activated carbon for control of mercury emissions from a municipal waste combustor equipped with a lime spray dryer absorber/fabric filter. The primary test objectives were to evaluate the effect of carbon type, feed rate, and feed location on mercury emissions and control efficiency. Secondary process parameters studied included the impact of ammonia injection for nitrogen oxides control, spray dryer outlet temperature, and spray dryer/fabric filter acid gas control efficiency on mercury removal. The time stability of mercury collected with ash was also studied. Conducted at the Ogden Martin Systems of Stanislaus, Inc. municipal waste combustor, near Modesto, CA, testing covered 16 system operating conditions, including normal unit operation and operation without ammonia injection. Test results showed that the two primary variables affecting both mercury emission and control efficiency were carbon feed rate and uncontrolled mercury levels. The results also indicated that mercury emissions were reduced by over 80% at high carbon addition rates. At low carbon feed rates, both the average mercury emissions rate and the variability in mercury levels during individual tests were significantly higher. The secondary parameters did not affect mercury control over the range of values tested.

Neme, C. 1991. Electric Utilities and Long-Range Transport of Mercury and Other Toxic Air Pollutants, November, 1991. Center for Clean Air Policy, Washington, D.C. 90p. (MESB 10/16/92)

The study reviews the health and environmental risks that utility emissions of trace metals may pose, evaluates the magnitude of utility emissions, and analyzes the technical and policy options for reducing utility emissions. Six findings are offered by the report, (1) mercury concentrations in fish, particularly in the Great Lakes region, have reached levels which may pose significant threats to human health, wildlife and the environmental integrity of the aquatic food chain, (2) a significant part of the problem of elevated mercury levels in fish and the aquatic food chain is attributed to atmospheric deposition, (3) until recently, the bulk of U.S. man-made mercury emissions have come primarily from fossil fuel combustion, municipal solid waste incineration and releases from latex paints, (4) fossil fuel combustion, particularly coal combustion by electric utility power plants, is also a major source of emissions of other trace metals, (5) electric utility emissions of mercury and other trace metals are not currently being regulated as air toxics under the Clean Air Act; the 1990 amendments to the Clean Air Act requires the USEPA to study whether such emissions should be regulated in the future, and (6) application of a combination of emission reduction options would be necessary to reduce utility emissions of mercury significantly below current levels.

NJDEPE. 1992a. Interim Report to the Commissioner of the New Jersey Department of Environmental Protection and Energy on the Findings and Recommendations of the Task Force on Mercury Emissions Standards Setting, December, 1992. New Jersey Department of Environmental Protection and Energy, Trenton. 21p. (MESB 1/27/93)

The interim report presents the regulatory, technical, environmental and health issues, and recommended procedures for implementation of recommended mercury emission standards for municipal solid waste incinerators. Cost estimates to achieve the recommended level of mercury emission reduction are also provided (1%-5% increase over present disposal fees). At present, most people in New Jersey do not appear to be at risk of ingesting excessive amounts of mercury through the consumption of fish. There exists, however, a potential for developmental health effects to the nervous system of children, exposed in utero to mercury, due to consumption by their mothers of fish containing methylmercury. The final report is anticipated to be available by the end of February 1993.

NJDEPE. 1992b. Task Force on Mercury Standard Setting Preliminary Report, September 1992. New Jersey Department of Environmental Protection and Energy, Trenton. 3 vol. 332p. (MESB 12/21/92)

The document is composed of 3 volumes, Executive Summary, Environmental and Health Issues and Technical and Regulatory Issues. Some of the preliminary findings include: (1) a strict mercury emission standard for municipal solid waste (MSW) incinerators is technologically and practically achievable through installation of new air pollution control equipment and implementation of source reduction and separation programs for waste products containing mercury; (2) the cost of achieving the recommended level of mercury emission reduction at MSW incinerators is considered to be reasonable with, for instance, the cost of installation of a carbon injection system onto existing incinerators to be about \$.50 per ton of solid waste burned; (3) evidence of a direct link between mercury emissions from MSW incinerators and adverse human health is inconclusive; (4) the most probable pathway to human exposure from mercury is through fish ingestion; (5) at present, most people in New Jersey do not appear to be at risk of ingesting excessive amounts of mercury through the consumption of fish. There exists, however, a potential for developmental health effects to the nervous system of children, exposed in utero to mercury, due to consumption of fish containing methylmercury; (6) there is a need for further research, review and evaluation of health and environmental data, (7) a technological achievable standard should be established which minimizes mercury emissions from MSW incinerators, and (8) further analysis should be conducted on other sources of mercury in the environment.

Volume two of the report addresses the Environmental and Health Issues. Some of the recommendations of this volume include: (1) until more precise information is available, the Average Daily Intake of 0.07 µg/kg/day should be considered the health basis for the establishment of a mercury emission standard for MSW incinerators, (2) mercury emissions from MSW incinerators should be reduced by greater than 95% of current levels and additional source categories, such as coal-fired power plants, land application of sludge and leaching of mercury from landfills should be considered for modeling and possible emission reduction.

Volume three of the report addresses the Technical and Regulatory Issues. This volume looks at documentable (from the literature and regulatory programs) emissions from MSW incinerators, coal-burning utilities, sludge

incinerators, crematories, fuel oil combustion, natural gas and gasoline, other smaller incineration operations and industrial sources. Based on the available information, estimates were developed in order to determine which of these sources contributed the greatest amount of mercury to the atmosphere. The data for several of the estimates were limited. The report also reviewed and evaluated available methods of prevention, reduction and control of the mercury emissions from the above sources. MSW incinerators were the focus of the investigation. An emission limit of 28 µg/dscm, at 7% oxygen, was suggested for MSW incinerators.

NUS Corporation. 1990. Characterization of Municipal Waste Combustion Ash, Ash Extracts and Leachates [pp E-1 - E-11 & 7-21, 7-25]. Office of Solid Waste, March, 1990. EPA530-SW-90-029A. U.S. Environmental Protection Agency, Washington, D.C. (MESB 2/2/93)

The study collected combined bottom and fly ash samples from 5 mass-burn municipal solid waste facilities and leachate samples from the companion ash disposal facilities. The leachate samples were analyzed for semi-volatile compounds, PCDDs/PCDFs, metals for which federal primary and secondary drinking water standards exist and several miscellaneous conventional compounds. The ash samples were subjected to 6 laboratory extraction procedures and the extracts were then analyzed. None of the leachate samples exceeded the EP Toxicity Maximum Allowable Limits established for the eight metals in Section 261.24 of 40 CFR 261. The EP Toxicity Maximum Allowable Limits for lead and cadmium were frequently exceeded by the extracts from the EP Toxicity, TCLP 1, and TCLP 2 extraction procedures. One of the extracts from the EP Toxicity extraction procedure also exceeded the EP Toxicity.

Olson, B.H. and R.C. Copper. 1976. Comparison of aerobic and anaerobic methylation of mercuric chloride by San Francisco Bay sediments. Water Res., 10:113-116. (MESB 3/15/93)

Methylation of mercury under aerobic and anaerobic condition was examined in 3 types of sediment collected from San Francisco Bay. The net amount of methylmercury produced under anaerobic conditions was greater than that found under aerobic conditions for all 3 sediments tested. The amount of organic matter in sediments greatly affected methylation capability. There are indications that methylmercury produced in anaerobic sediments is more stable than that produced in aerobic sediments.

Peterson, D.E., M.S. Kanarek, M.A. Kuy Kendall, J.M. Diedrich, H.A. Anderson, P.L. Remington and T.B. Sheffy. 1991. Fish Consumption Patterns and Blood Mercury Levels in Wisconsin Chippewa Indians. Paper presented at the April 1991 Epidemic Intelligence Service Conference, Atlanta, Georgia. 24p. (MESB 1/18/93)

Wisconsin Chippewa Indians were studied to determine the extent of their exposure to methylmercury as a result of their taking large amounts of mercury contaminated fish from northern Wisconsin lakes. Methylmercury levels in some Chippewa Indians were elevated but below the levels associated with adverse health effects. Continuing efforts to limit exposure to the high-risk population were recommended.

Porcella, D. [1992]. Presentation: Update on Mercury Research Program, December 14, 1992, p. 2-8. IN Harrison, K.G. (ed.) Michigan Environmental Science Board Mercury Panel Meeting Minutes, Monday, December 14, 1992. Michigan Environmental Science Board, Lansing, Michigan. 19p. (MESB Minutes 12/14/92)

Porcella presented a review of current issues and the Electric Power Research Institute (EPRI) research program on environmental mercury. It had been assumed that emissions translated directly into depositions, but that is not necessarily true. The kinetics of transport, wet and dry deposition, and scavenging are not well understood. EPRI has launched a comprehensive program of research on emissions, atmospheric transport and transformation, ecological cycling, fish accumulation, and risk assessment and human health. New methods of speciation and measurement of mass balance have been developed, and EPRI has plans for plume measurement work as sensitive measurement techniques become available. The presentation outlined the best current measures of global mercury, from both natural and anthropogenic sources, discussed clean measurement techniques and presented the development and some results of the EPRI cycling model; describing the mass balance of a Wisconsin lake. It was noted that water chemistry in local lakes seems to be responsible for measured differences in mercury content.

Premo, B.J. [1993]. Report to the Michigan Environmental Science Board (MESB) on Mercury in Surface Water and Fish, January 26, 1993. Michigan Environmental Science Board, Lansing. 8p. (MESB 1/27/93)

Paper reviews and summarizes pertinent literature on sources and pathways of mercury in the environment and the means by which humans and wildlife are exposed. Paper also discusses current problem with the Michigan Water Quality Standard for mercury and permit levels established for surface water dischargers (all permittees are currently allowed discharge of total mercury as long as it is below 0.2 µg/l. This level is over 150 times the level mandated by the Michigan Water Quality Standards). Another problem addressed is the concern regarding whether the Michigan Water Quality Standard correctly identifies a standard for total mercury or methylmercury. Options for reducing mercury in the environment, recommendations for further studies and educational needs are also presented.

Rothstein, R.A., B. Clemence and P.J. Stoller. 1991. Issues Associated with Environmental and Permit Evaluations of Mercury Emissions from Municipal Waste Combustors. Paper presented at the November 11-14, 1991 Air, Water and Waste Technologies Conference, Engineering Soc. of Detroit and Michigan, Detroit. 38p. (MESB 3/12/93)

The paper summarizes the current understanding of the behavior of mercury in the environment, characterizes mercury in the waste stream and potential stack emissions, reviews environmental fate and transport issues and discusses recent developments in control technology and regulatory policy. Considerations for performing mercury impact assessments using multi-media modeling techniques are discussed. Also presented is a review of further stack emission, field research, and regulatory modeling needs to help properly ascertain existing source contributions to observe mercury levels in

freshwater fish and potential impacts from proposed new sources.

Schmitt, C.J. and W.G. Brumbaugh. 1990. National contaminant bio-monitoring program: concentrations of arsenic, cadmium, copper, lead, mercury, selenium and zinc in U.S. freshwater fish, 1976-1984. Arch. Environ. Contam. Toxicol., 19:731-747. (MESB 11/6/92)

From late 1984 to early 1985, the U.S. Fish and Wildlife Service collected a total of 315 composite samples of whole fish from 109 stations nationwide. Mean concentrations of lead, arsenic, cadmium, and selenium declined from 1976 to 1984; lead did so significantly. Mean concentrations of mercury, copper and zinc did not change.

Schroeder, W.H., G. Yarwood and H. Niki. 1991. Transformation process involving mercury species in the atmosphere - results from a literature review. Water, Air and Soil Pollution, 55:653-666. (MESB 3/24/93)

Mercury is released into the atmosphere from natural and anthropogenic sources. Once in the air, mercury species will be dispersed, chemically and physically transformed, and transported over varying distances (regional, continental and global scales) while concurrently being subjected to removal processes. Modeling of the aerial transport and deposition of mercury to receptor sites offers an attractive approach for integrating existing experimental data and represents an important tool for advancing the understanding of environmental mercury pollution. Comprehensive modeling efforts of the atmospheric chemistry. To update and consolidate available information relevant to the atmospheric chemistry of mercury, a computer-assisted search was undertaken of the primary scientific literature published during the last 10 years. Selected results from this literature survey are presented.

Shieh, C.S. 1992. The specific role of waste-to-energy facilities in environmental cycling of mercury. IN International Conference on Mercury as a Global Pollutant, May 31 - June 4, 1992 [Abstracts Only]. Electric Power Research Institute, U.S. Environmental Protection Agency, Vattenfall and Environmental Canada: AES, Monterey, California. 133p. (MESB 10/21/92)

Studies were conducted to evaluate the significance of mercury input from the combustion of municipal solid waste (MSW) at waste-to-energy (WTE) facilities. Because mercury is contained in varying components of MSW, combustion of MSW at WTE facilities provides and additional input of mercury to the environment. During combustion, mercury contained in MSW was released to the environment either by emission or by the production of solid residues. Waste-to-energy facility is increasingly becoming an important component in the integrated management of MSW. However, by-products of the combustion of MSW have received significant attention due to their specific characteristics and massive production. It is estimated that, in the U.S., 108 million tons of MSW will be combusted by the year 2000. Similar to the combustion of coal, unburned residues such as bottom ash, fly ash, and scrubber residues are produced during the combustion of MSW. A 70% reduction in the weight of MSW combusted is normally achieved at WTE facilities. Therefore, approximately 32 million tons of WTE ash residues will be produced every year.

Air pollution and solid waste production are two major concerns when WTE facility are operated. The amount of mercury released to the atmosphere by WTE facilities can be estimated from the amount of MSW burned using the average mercury content of the MSW and a release factor. Mercury is contained in certain components of MSW, such as used battery, fungicides in paints, thermometers, electronic components and fluorescent tubes. The estimated production rate of mercury in WTE ashes would be  $66.2 \times 10^6$  per year. Approximately 20% of mercury in MSW combusted is retained in ash residues. A release factor of 0.8 is, therefore, obtained for the emission of mercury to the atmosphere.

Shubat, P. 1991. Health Risk Assessment for the Consumption of Sport Fish Contaminated with Mercury: Guidelines for the 1991-1992 Minnesota Fish Consumption Advisory, January 1991. Minnesota Department of Health, Minneapolis. 11p. (MESB 11/6/92)

Provides background for the development of the Minnesota Fish Consumption Advisory. The methylmercury reference dose used to serve as the basis for the advisory was 0.3 µg/kg/day.

Silver, S. and T.K. Misra. 1988. Plasmid-mediated heavy metal resistances. Ann. Rev. Microbiol., 42:717-743. (MESB 3/15/93)

Authors provide an updated literature review of plasmid-mediated heavy metal resistances in light of recent advances in the cloning and DNA sequence analysis of determinants for mercury, arsenic, cadmium and tellurium resistance. Review broadly covers plasmid-determined heavy metal resistances. Heavy metal resistant strains isolated from environmental or clinical sources generally have these resistances on plasmids or on transposons, or at least the genetic determinants are homologous to those found on plasmids. Chromosomal mutations to heavy metal resistance can be produced in the laboratory but do not generally occur in nature. In this regard toxic heavy metal resistances are comparable to antibiotic resistances; e.g., streptomycin resistance found in natural isolates is always due to aminoglycoside-inactivating enzymes and not to the modified ribosomal protein that is responsible for laboratory-selected resistance to streptomycin. The chromosomally determined mutations leading to arsenate, cadmium, chromate, and cobalt resistances are due to changes in the membrane transport systems responsible for uptake of the beneficial analog of these toxic materials; i.e., phosphate, manganese, sulfate, and magnesium, respectively. For most resistances except cadmium resistance, and most notably for mercurial and arsenic resistances, single biochemical mechanisms seem to be widespread among all bacterial types tested.

Slemr, F. and E. Langer. 1992. Increase in global atmospheric concentrations of mercury inferred from measurements over the Atlantic Ocean. Nature, 355:434-437. (MESB 3/19/93)

Anthropogenic processes, such as coal burning, waste incineration and ore refining, are believed to contribute to the emission of mercury into the atmosphere. The atmospheric concentration of mercury should therefore have increased as a consequence of increases in anthropogenic emissions. Indeed,

analyses of dated soil, peat bog and lake-sediment records indicate that the deposition of atmospheric mercury may have doubled since the beginning of the nineteenth century. But such an increase in atmospheric mercury concentration has so far not been detected in ice-core records (perhaps because of problems with contamination), and is not consistent with most mercury budgets, in which natural sources are thought to dominate. Measurements are presented of total gaseous mercury over the Atlantic Ocean for 1977-90, which show that atmospheric concentrations of mercury have in fact increased by  $1.46 \pm 0.17\%$  per year in the Northern Hemisphere, and by  $1.17 \pm 0.16\%$  per year in the Southern Hemisphere. These rates of increase are consistent with the results of the soil, peat bog and lake-sediment analyses, and lead to the suggestion that anthropogenic, rather than natural, sources are at present more important in the mercury cycle.

Soos, P. [1992]. Comments on the MDNR's "Mercury in Michigan's Environment" report, October 15, 1992. Correspondence to Michigan Environmental Science Board. Ogden Martin Systems, Inc, Fairfield, New Jersey. 2p. (MESB 10/19/92)

Correspondence critiques literature and data interpretation by the Michigan Department of Natural Resources (MDNR) in its 1992 draft report on mercury (see MDNR 1992c). Most of the concern relates to MDNR statements and conclusions regarding municipal waste incinerators and their impact on the levels of mercury emissions.

Stinson, C.H., D.M. Shen, T.M. Burbacher, M.K. Mohamed and N.K. Mottet. 1989. Kinetics of methylmercury in blood and brain during chronic exposure in the monkey Macaca fascicularis [Abstract Only]. Pharmacol. Toxicol., 65(3):223-230. (MESB 2/19/93)

The disposition parameters derived from a compartmental model kinetic analysis of blood mercury levels in nonpregnant, adult female Macaca fascicularis given daily doses of methylmercury did not vary with either dosage level (50, 70 or 90  $\mu\text{g}$  methylmercury/kg b.wt.day) or duration of exposure (up to 507 day). In contrast, blood clearance of mercury in pregnant females was dose-dependent; it being higher at the 90  $\mu\text{g}$  methylmercury/kg b.wt.day than at the lower dosage levels. Mercury levels in the brain of adult fascicularis relative to blood mercury also increased at the highest level of exposure. Blood mercury half-life in neonate fascicularis was similar to half-life in their mothers (adults). Finally, the regional distribution of mercury in the brains of adult and neonate fascicularis exposed to low and intermediate levels of methylmercury resembles the reported distribution of mercury in the brains of adult and neonate humans environmentally exposed to methylmercury. Consequently, M. fascicularis may be an especially appropriate animal model for studying the neurotoxic mechanisms of chronic methylmercury exposure.

Summers, A.O. 1986. Organization, expression and evolution of genes for mercury resistance. Ann. Rev. Microbiol., 40:607-634. (MESB 3/15/95)

Paper reviews the mechanisms which result in mercury resistance in gram-negative and gram-positive bacteria. A possible evolutionary protocol is suggested for both.



Summers, A.O. and S. Silver. 1978. Microbial transformation of metals. Ann. Rev. Microbiol., 32:637-672. (MESB 3/15/93)

Paper provides an extensive literature review about what is known of the biochemistry and genetics of microbial metal transformation and puts the biochemical and genetic data into context of the known ecological and bacterial data on such transformations.

Summers, A.O., J. Wireman, M.J. Vimy and F.L. Lorscheider. 1990. Increased mercury resistance in monkey gingival and intestinal bacterial flora after placement of dental "silver" fillings [Abstract Only]. Physiologist, 33:116. (MESB 3/15/93)

Mercury vapor is continuously released from silver amalgam fillings in humans. However, the bioavailability and toxicological relevance of this mercury exposure is uncertain. Since an increase in mercury resistant bacteria in response to mercury contamination of soil or water is an indication of bioavailability of mercury in the environment, the authors examined whether the incidence of such bacteria in the gingival and fecal flora is altered following placement of amalgam tooth fillings. Occlusal fillings (16, total mercury 1500 mg) were inserted into two adult male cynomolgus monkeys under general anesthesia, using standard dental procedures. Duplicate samples (12) of fecal and gingival microbial flora were taken from each monkey during 10 days prior and 30 days after amalgam placement. Samples were cultured for gram-positive facultative fecal bacteria. Primary isolates were screened to determine the proportion resistant to mercury and to arsenate and tetracycline, agents to which bacterial resistance is found in nature. While arsenate and tetracycline resistance were detected continuously in all cultures, mercury resistance was undetectable until the 10th day after amalgam placement. Thereafter, levels of mercury resistance in gingival and fecal flora ranged from 1 to 100%, averaging 30% in both monkeys until termination. From the 3rd-30th day total fecal mercury excretion averaged 300 µg/animal/day. Thus, ingested mercury is sufficiently bioavailable to select for a substantial increase in the proportion of mercury resistant bacteria in both the oral cavity and the intestine. Since mercury resistant bacteria convert mercury-two or methylmercury to volatile, lipid soluble mercury, the increased incidence of such bacteria in flora may influence the pharmacodynamics and toxicity of ingested mercury from dental amalgam.

Swain, E.B. and D.D. Helwig. 1989. Mercury in fish from northeastern Minnesota lakes: historical trends, environmental correlates and potential sources. J. Minnesota Academy Sci., 55:103-109. (MESB 1/15/93)

Analysis of sediments from remote northeastern Minnesota lakes containing fish with elevated mercury concentrations was conducted. The analysis suggests that mercury deposition has increased by a factor of about 3.5 since white settlement in the state. Because the increase is spatially constant across northeastern Minnesota, it is hypothesized that atmospheric pollution was responsible for the increase. Given that fish mercury varies considerably among lakes, local environmental processes apparently control the conversion of inorganic mercury into the methylmercury found in the fish. The concentration of mercury in Minnesota fish is related to water chemistry,

which in turn is influenced by the geology of the watershed. Fish from lakes in watersheds rich in limestone are less likely to have high mercury concentrations than lakes in low-alkalinity regions. Lakes with water colored from peat lands are more likely to contain fish with high mercury concentrations. Trend analysis shows that mercury concentrations in fish increased significantly between the 1930's and 1980's (comparison between museum specimens and recent samples) and between the 1970's and 1980's. The rate of increase of mercury concentrations is highest in low-alkalinity lakes.

Taylor, J.K. [1993]. Update on the Clean Air Act (CAA). Correspondence to the Michigan Environmental Science Board, February 2, 1993. Michigan Department of Natural Resources, Lansing. 4p. (MESB 2/3/93)

Correspondence presents an update on the Clean Air Act (CAA) studies summarized in the CAA section of the June 24, 1992 draft Michigan Department of Natural Resources report entitled, Mercury in Michigan's Environment Causes and Extent of the Problem (see MDNR 1992c). Updates are presented on the CAA sections on the Great Waters Study [112(m)], Utility Study [112(n)(1)(A)], Mercury Study [112(n)(1)(B)] and National Institute of Environmental Health Science's Study [112(n)(1)(C)].

Taylor, J.K. [1992a]. Clarification of the Attachment to the September 11, 1992 MESB Minutes. Correspondence to the Michigan Environmental Science Board, December 21, 1992. Michigan Department of Natural Resources, Lansing. 2p. (MESB 12/21/92)

Correspondence clarifies origin and purpose of the Michigan Department of Natural Resources document entitled, Michigan Environment with Respect to Mercury.

Taylor, J.K. [1992b]. FYI-LaFarge Corporation's Mercury Emissions. Memorandum to Rick Johns, April 20, 1992. Michigan Department of Natural Resources, Lansing. 1p. (MESB 3/3/93)

Memorandum documents an instance of an outstate shipment of mercury-laden wastes to Michigan kiln/hazardous waste incinerator for disposal. Taylor suggested that since this incineration facility was expanding, that this would be a good time to establish a permit limit for mercury for the facility.

TRC Environmental Corporation. 1993. Trends in Mercury Use and Disposal, Interim Final Report, January 13, 1993. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. 45p. (MESB 2/3/93)

Report reviews literature to examine trends in mercury use in several manufactured products and municipal waste combustion and fossil fuel combustion. Manufactured products addressed include household batteries, fluorescent lights, mercury lamps, electric switches, latex paints, thermometers, outdoor textiles and turf products. The report indicates that (1) the chloralkali industry is the largest user of mercury, (2) municipal waste incinerators are the fastest growing source of mercury emissions; a seven-fold increase is expected by the year 2010, (3) batteries represent the major source of mercury in municipal waste incinerators, (4) although expected

to decline, industrial incineration is still likely to be a significant source of mercury emissions, (5) medical waste contains 5 to 50 times more mercury than municipal waste and (6) the burning of fossil fuels is a significant source of mercury emissions to the air and that this source is expected to increase as energy demands increase.

Turner, M.D., D.O. Marsh, J. Chrispin-Smith, J.B. Ingles, T.W. Clarkson, C.E. Rubio, J. Chiriboga and C.C. Chiriboga. 1980. Methylmercury in populations eating large quantities of marine fish. Arch. Environ. Health, 35:367-375. (MESB 3/26/93)

A Peruvian population was identified that was chronically exposed to methylmercury from the long-term consumption of ocean fish. The weekly fish intake averaged 10.1 kg per average family of 6.2 persons. Blood methylmercury concentrations ranged from 11 to 275 ng/ml, with a mean of 82 ng/ml. Paresthesias were reported by 29.5% of the population. In contrast, a nearby control population had a mean weekly fish consumption of 1.9 kg per average family of 6.4 persons. Their blood methylmercury levels were 3.3-25.1 ng/ml, with a mean of 9.9 ng/ml. Paresthesias were reported by 49.5% of this control group. No individual was identified with symptoms or signs that could be attributed to methylmercury intoxication.

USEPA. 1993a. EPA Issues Great Lakes Water Quality Guidance, Press Release, March 31, 1993. U.S. Environmental Protection Agency, Chicago, Illinois. 3p. (MESB 4/8/93)

On March 31, 1993, the USEPA announced the release of its proposed quality guidance for the Great Lakes ecosystem. The Great Lakes Water Quality Guidance (GLWQG) will require the 8 Great Lakes states and certain Indian tribes to establish consistent, scientifically-based controls on toxic pollutants in the Great Lakes basin.

According to the USEPA, the GLWQG will result in consistent, basin-wide water quality standards designed to protect human health, aquatic life and wildlife. The guidance proposes human health criteria for 20 pollutants, aquatic life criteria for 16 pollutants and wildlife criteria for 4 pollutants. The guidance contains methodologies for developing additional criteria and values for the protection of human health, aquatic life and wildlife.

The GLWQG also includes proposed detailed provisions on antidegradation and detailed requirements for establishing or implementing important elements of National Pollutant Discharge Elimination System permits and water quality programs.

The proposed guidance is to be published in the Federal Register followed by a 150-day written public comment period. The USEPA will also hold a public hearing on August 4th and 5th at its regional office in Chicago.

USEPA. 1993b. EPA releases new regs for managing sludges. Solid Waste & Power, 7(1):6. (MESB 3/3/93)

Article announces the publication of new rules (February, 1993) which set numerical limits for 12 pollutants in sludge including arsenic, cadmium, lead and mercury.

USEPA. 1992. Characterization of Products Containing Mercury in Municipal Solid Waste in the United States, 1970 to 2000, April 1992. Office of Solid Waste, Washington, D.C. EPA530-R-92-013. 135p. (MESB 10/16/92)

The report identifies the products in municipal solid waste that may contain mercury and quantifies the mercury present in the products. The data presented are for the period 1970 to 1980 and estimates are projected to the year 2000. The data show that household batteries, although projected to be decreasing by the year 2000, have been and will continue to be the largest single source of mercury into the municipal solid waste stream of the mercury-containing products. Other products identified as contributing to the waste stream include, electric lighting, paint residues, fever thermometers, thermostats, pigments, dental uses, special paper coating, mercury light switches and film pack batteries. Overall, the report projects a decrease in the contribution of mercury to municipal solid waste incinerators from mercury-containing products by the year 2000.

Van Maele, L. 1990. Household Battery Collection and Storage, March 1990. Legislative Services Bureau, Lansing, Michigan. 5p. (MESB 12/9/92)

Information on options for collection and storage of spent household batteries is presented. Two major battery manufacturers, two recycling programs, and a company reclaiming mercury and silver from collected spent batteries were interviewed about safe storage and transport methods. Only one documented accident was reported.

Veltman, J.C. and M.D. Maines. 1986. Alterations of heme, cytochrome P-450, and steroid metabolism of mercury in rat adrenal [Abstract Only]. Arch. Biochem. Biophys., 248(2):467-478. (MESB 2/19/93)

The treatment of male rats with mercury-two resulted in significant alterations in heme and hemoprotein metabolism in the adrenal gland which, in turn, were reflected in abnormal steroidogenic activities and steroid output. Twenty-four hours after the administration of 30  $\mu$ mol of mercuric chloride/kg the mitochondrial heme and cytochrome P-450 concentrations increased by approximately 50%. Also, mercury-two treatment stimulated a porphyrinogenic response which included an 11-fold increase in the activity of delta-aminolevulinate synthetase. The increase in mitochondrial cytochrome P-450 content was reflected in elevated steroid 11 beta-hydroxylase and cholesterol side-chain cleavage activities. In contrast, mercury-two treatment resulted in decreased concentrations of microsomal cytochrome P-450 (-75%) and heme (-45%). Similarly, the reduction in the microsomal cytochrome P-450 content was accompanied by reduced steroid 21 alpha-hydroxylase and benzo [alpha] pyrene hydroxylase activities. The mechanisms responsible for the loss of the microsomal cytochrome P-450 content appeared to involve a selective impairment of formation of the holocytochrome as well as an enhanced rate of heme degradation. This suggestion is made on the basis of findings that (a) the decrease in the microsomal cytochrome P-450 content was accompanied by a 7

fold increase in the activity of adrenal heme oxygenase, (b) no decrease in apocytochrome P-450 could be detected in sodium dodecyl sulfate-gel electrophoresis of the solubilized microsomal fractions stained for heme, and (c) the concentration of adrenal microsomal cytochrome b5 was significantly increased in the mercury-two-treated animals. It is suggested that mercury-two directly caused a defect in adrenal steroid biosynthesis by inhibiting the activity of 21 alpha-hydroxylase. The apparent physiological consequences of this effect included lowered plasma levels of corticosterone and elevated concentrations of progesterone and dehydroepiandrosterone. This abnormal plasma steroid profile is indicative of a 21 alpha-hydroxylase impairment.

Volland, C.S. 1992. Paper #92-40.1, Emissions of Volatile Heavy Metals from Medical Waste Incinerators, 16p. Paper presented at the 85<sup>th</sup> Annual Meeting & Exhibition, Kansas City, Missouri, June 21 - 26, 1992. Air & Waste Management Association, Pittsburgh, Pennsylvania. (MESB 3/3/93)

Paper concludes that medical waste incinerators are a significant source of mercury to the environment. Unlike municipal solid waste incinerators where buildup in fish is the sole risk pathway, medical waste incinerators could also pose an inhalation risk near the facility. Paper indicates that hospitals and other developers of medical waste incinerators need to provide controls that will capture metal vapors. Mercury-bearing waste source control is feasible at local hospitals but is not practical at regional or commercial disposal facilities.

Volland, C.S. 1991. Paper 91-35 1. Mercury Emissions from Municipal Solid Waste & Combustion, 18p. Paper presented at the 84<sup>th</sup> Annual Meeting & Exhibition, Vancouver, British Columbia, June 16 - 21, 1991. Air & Waste Management Association, Pittsburgh, Pennsylvania. (MESB 3/3/93)

Paper presents an overview of the current understanding of the sources, concerns, and technological controls of municipal solid waste (MSW) incineration mercury emissions. Topics discussed include, (1) Sources and fate of mercury in MSW, (2) Effects of removing batteries, (3) Mercury emission spikes, (4) Mercury emission variables, (5) The question of permanent capture, (6) Advanced mercury removal methods, (7) Ecological impacts of mercury emissions from MSW incinerators, and (8) Mercury emission standards.

Watras, C.J., N.S. Bloom, W.F. Fitzgerald, J.P. Hurley, D.P. Krabbenhoft, R.G. Rada and J.G. Wiener. 1989. Mercury in temperate lakes: a mechanistic field study [Abstract Only]. Verh. Internat. Verein Limnol., IVL 476 DA 43-6802. (MESB 3/24/93)

Improvements in sampling protocols and advances in analytical techniques recently have made possible detailed studies of the mercury cycle in pristine lakes. The concentrations of several mercury species in lakewater, groundwater, precipitation, air, sediments and the biota of six Northern Wisconsin lakes that vary along pH and dissolved oxygen concentration continua. Using trace-metal-clean sampling protocols adapted from marine studies and analytical techniques with very low detection limits the initial data show that mercury concentrations in lakewater are quite low and approach the levels observed in open-ocean areas. Lakewater mercury concentrations are

comparable to, if not lower than, precipitation levels, suggesting that the atmosphere is a major source of mercury to lakes in this mid-continental region. Biotic mercury concentrations tend to be  $10^4$  to  $10^6$  times higher than lakewater concentrations and are similar to mercury concentrations found in organic sediments. Thus, the movement of mercury from the atmosphere to lakewater and then to biotic particles that settle fairly fast seems an important pathway for mercury in these precipitation-dominated systems. Seasonal depth profiles have shown that stratified lakes are quite dynamic with respect to mercury. Mercury concentrations may increase 10 to 40-fold (depending on the mercury species) in hypolimnetic waters during peak stratification. The cause of this hypolimnetic enrichment is unclear, but it probably involves either the release of mercury from deep plankton layers or from surficial sediments due to redox reactions. In one acidic lake hypolimnetic mercury concentrations decreased to epilimnetic values after mixis. The total mass of mercury in lakewater decreased by about 50% after overturn, but the fate of the hypolimnetic mercury is unknown. In an experimental acidified lake, mercury concentrations in fish tissue (Perca flavescens) have increased as the pH has decreased. Since mercury loading to the lake is not a factor here, these data demonstrate that mercury bioavailability changes as a function of acidity.

West, P.C., J.M. Fly and F. Larkin. 1989. Michigan Sport Anglers Fish Consumption Survey: A Report to the Michigan Toxic Substance Control Commission. Natural Resource Sociology Research Lab Technical Report #1, University of Michigan, Ann Arbor. 152p. (MESB 2/19/93)

The University of Michigan, under contract to the Michigan Toxic Substance Control Commission, undertook an investigation to determine the validity in Michigan of the national average fish consumption value of 6.5 grams/person/day. The investigation was a mail survey of a stratified sample of sport fish license holders. The total sample size was 2,600. The sample of 2,600 was spread in 18 randomly drawn cohorts over the period from mid January to early June 1988. The final response rate was 47.4 percent. The mailed survey found that average fish consumption was 18.3 grams/person/day [A follow up survey was conducted by the University of Michigan with a sample of respondents and non-respondents to test for non-response bias. The non-response survey found that there was indeed a non-response bias in the mail survey; those who did not return the surveys tended to eat less fish. As a consequence of the survey the average fish consumption was reduced from 18.3 grams/person/day to 17.1 grams/person/day]. The results also showed that Native Americans in the sample consumed more fish than blacks (24.4 grams/person/day vs 20.3 grams/person/day) and that both minorities consumed more fish than whites in the survey (17.9 grams/person/day). Based on the results of the investigation, it was concluded that the national average fish consumption value of 6.5 grams/person/day was highly questionable in Michigan.

White, D.M., K.L. Nebel, T.G. Brna and J.D. Kilgroe. 1992. Parametric Evaluation of Powdered Activated Carbon Injection for Control of Mercury Emissions from a Municipal Waste Combustor. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. USEPA 92-40.06. 16p. (MESB 10/22/92)

Radian Corporation conducted a series of tests to evaluate the injection of powdered activated carbon into municipal waste combustor flue gas to control mercury emissions. They were conducted in the summer of 1991 on Unit 2 of the Ogden Martin Systems of Stanislaus, Inc. facility in California. The tests were designed to determine the effects of carbon type, feed location, and feed rate on mercury removal. The other operating parameters tested were ammonia injection, lime feed rate and fabric filter temperature. Activated carbon made from coal, lignite based carbon, and wood-based carbon were used. Feed rates varied from 1.3 to 8.3 kg/hr. Carbon injection locations were near the spray dryer outlet, the economizer outlet and with the lime slurry. Based on the results of the testing and the statistical analysis of the data, varying carbon type and feed location did not significantly influence the results. The statistical analysis did indicate, however, that carbon feed rate had a significant impact on mercury removal for all carbon feed locations and types. As expected, increased feed rate increased mercury removal and lowered stack mercury concentrations. Higher feed rates also decreased the variability of mercury control performance. Low carbon feed rates resulted in both lower mercury control efficiency and greater run-to-run variability in mercury reduction performance. The impact of ammonia injection appears to be minor, fabric filter temperature did not affect removal, and there was no correlation between lime feed rate and removal.

WHO. 1990. Environmental Health Criteria 101, Methylmercury. World Health Organization, Geneva, Switzerland. 143p. (MESB 3/23/93)

The document focuses on the risks to human health from compounds of monomethylmercury and examines the data which have become available since 1976. According to the report, the general population does not face a significant health risk from methylmercury. Certain groups with a high fish consumption may attain a blood methylmercury level (about 200 µg/l, corresponding to 50 µg/g of hair) associated with a low (5%) risk of neurological damage to adults.

The fetus is a particular risk. At peak maternal hair mercury levels above 70 µg/g there is a high risk (more than 30%) of neurological disorder in the offspring. A prudent interpretation of the Iraqi data implies that a 5% risk may be associated with a peak mercury level of 10-20 µg/g in maternal hair.

Wiener, J.G., W.F. Fitzgerald, C.J. Watras and R.G., Rada. 1990. Partitioning a bioavailability of mercury in an experimentally acidified Wisconsin lake. Environmental Toxicology and Chemistry, 9:909-918. (MESB 3/19/93)

The partitioning of mercury among air, water, sediments and fish was studied at Little Rock Lake; a clear water seepage lake in north-central Wisconsin. The lake was divided with a sea curtain into 2 basins, one acidified with sulfuric acid to pH 5.6 for 2 years and the other an untreated reference site (mean pH 6.1), to document the effects of acidification. Trace-metal-free protocols were used to measure mercury at the picomolar level in air and water. Total gaseous mercury in air samples averaged 2.0 ng/m<sup>3</sup>. Total mercury in unfiltered water samples collected in 1986 after the fall overturn averaged about 1 ng/l in the acidified and reference basins. Mercury in surficial sediments was strongly correlated with volatile matter content and

ranged from 10 to about 170 ng/g (dry weight) in both basins. Total mercury concentrations in whole, calendar age-1 yellow perch (Perca flavescens), sampled after one year of residence in the lake, average 114 ng/g (fresh weight) in the reference basin and 135 ng/g in the acidified basin—a highly significant ( $p < 1$ ) difference. The mean whole-body burden (quantity) of mercury in age-1 perch did not differ between basins after the first year, but was significantly greater in the treatment basin than in the reference basin after the second year of acidification. Differences between the 2 basins in the bioaccumulation of mercury were attributed to internal (within-lake) processes that influence the bioavailability of the metal. An initial mercury budget for the treatment basin of Little Rock Lake showed that atmospheric deposition and sedimentary remobilization of mercury are potentially important processes influencing its biogeochemical cycling and uptake by fish.

Wiener, J.G., D.E. Powell and R.G. Rada. 1992. Mercury accumulation by fish in Wisconsin seepage lakes: relation to lake chemistry and acidification. IN International Conference on Mercury as a Global Pollutant, May 31 - June 4, 1992 [Abstracts Only]. Electric Power Research Institute, U.S. Environmental Protection Agency, Vattenfall and Environmental Canada: AES, Monterey, California. 133p. (MESB 10/21/92)

The bioaccumulation of mercury by yellow perch Perca flavescens was studied in relation to the chemistry of seepage lakes in northern Wisconsin. The effect of acidification on bioaccumulation was studied in Little Rock Lakes, which was separated into a reference basin (mean pH 6.1) and a treatment basin that was acidified with sulfuric acid for 2 years at pH 5.6, 2 years at pH 5.2, and 2 years at pH 4.7. Mean concentrations of mercury in whole age-1 yellow perch, sampled annually, were greater in treatment-basin fish than in reference fish during 5 of the 6 years. Mercury concentrations in perch populations in 3 nearby seepage lakes with mean pH of 5.2, 6.1, and 7.2 were also inversely related to pH; the bioaccumulation of mercury in these populations paralleled their rates of growth, indicating that diet was the primary route of mercury uptake. The mercury content of yellow perch varied among 3 lakes that has similar mean pH (about 6.1) but differing concentrations of dissolved organic carbon (DOC), but not in relation to DOC. The mercury content of fish was greatest in the high-DOC lake, intermediate in the low-DOC lake, and lowest in the intermediate-DOC lake.

Widenman III, A.J. [1992]. Concentrations of Mercury in Coal - EPRI Version Technical & Engineering Services Report 92A23-01. Memorandum to M.F. Rodenberg, January 28, 1992. Detroit Edison, Detroit. 28p. (MESB 1/15/93)

The study analyzed the concentration of mercury in fossil fuels used by Detroit Edison. Five plants burn significant percentages of High-Mid-and Low-Sulfur Eastern Appalachian coals and have the potential to emit the largest amounts of mercury. Two plants burn only Upper Powder River Basin Coals and have the potential to emit the lowest amounts of mercury. For western coals, Lower Powder River Basin coals generally have high mercury concentrations; whereas, Upper Powder River Basin coals generally have low mercury concentrations. High-Sulfur Easter coals have the largest mercury concentration. One plant which burns raw and washed Low-Sulfur Appalachian coals demonstrated low mercury concentrations in the 2 coals. Raw Low-Sulfur



Eastern Appalachian coal from Mine #09 showed the lowest concentration of mercury of all the coals tested. This coal also showed the lowest sulfur concentration among the Low-Sulfur Eastern Western coals. Analyses of #2 and #6 fuel oils burned by Detroit Edison exhibited concentrations 2-3 magnitudes less than coal.

Wolff, G.T. [1993]. Mercury Report, Version 1.0, January 26, 1993. Michigan Environmental Science Board, Lansing. 10p. (MESB 1/27/93)

Paper discusses existing concentrations of mercury found in ambient air and precipitation, anthropogenic sources of atmospheric mercury, relationship between atmospheric mercury deposition and observed mercury concentrations in surface water and fish, and chemical and physical mechanisms of mercury deposition. The paper also presents several recommendations for further study.

Wren, C.D. 1991. Cause-effect linkages between chemicals and populations on mink (Mustela vison) and otter (Lutra canadensis) in the Great Lakes basin. J. Toxicol. Environ. Health, 33:549-585. (MESB 3/26/93)

Following outbreaks of reproductive failure in commercial ranching operations, laboratory experiments showed that mink are extremely sensitive to organochlorine chemicals, particularly PCBs and dioxins. The purpose of this paper was to test the hypothesis that, since wild mink are exposed to these compounds through consumption of Great Lakes fish, they might exhibit reproductive dysfunction and population declines. The otter, another piscivorous animal, should show the same effects. The available information is reviewed according to five epidemiological criteria.

Harvest data are presented as a surrogate for the population status of mink and otters in certain locations around the Great Lakes. Data from Ohio show that the mink harvest between 1982 and 1987 from contaminated counties bordering Lake Erie was consistently lower (380 animals per year) than those from counties removed from Lake Erie (850 animals per year), suggesting an effect of chemicals on the status of mink populations. Preliminary studies from Ontario also suggest that mink harvest is lower in potentially "high PCB exposure areas" compared with lower exposure areas. Evidence is also presented on the harvest data for otters taken from 4 New York counties adjacent to Lake Ontario and the St. Lawrence River. The harvest data from the 4 counties show that between 1960 and early 1970 otter harvest remained stable but has since increased. Increased harvest is consistent with improved water quality in Lake Ontario during the past 15 years.

Data relating to strength of association between chemicals and populations of mink and otter are weak and need to be further analyzed. The specificity of the effects of the chemicals on mink reproduction and mortality is well established from toxicological experiments, but there is poor resolution of the information on effects using field data. The strongest case for a causal relationship comes from consideration of the coherence criterion.

In conclusion, before a causal link can be drawn between the status of mink and otter populations and exposure to organochlorine chemicals from the Great

Lakes, a large amount of research and data analysis needs to be undertaken.

Ziff, S. and M.F. Ziff. 1992. Dental mercury - an environmental hazard. Bio-Probe Newsletter, 8(5):1-6. (MESB 10/19/92)

Report relates findings from Swedish investigations regarding the impact of dental amalgam on the mercury environmental contamination problem. It makes various estimates to derive an annual mercury loading from dental mercury to the U.S. (130,752 lbs). The article highlights the points of a plan which was submitted by the Swedish Socialstyrelsen to the Swedish government to phase out the use of amalgam over the next 5 years.

### APPENDIX III

#### *Draft Toxicological Profile for Mercury\**

---

\* Source:

Clement International Corp. 1992. Chapter 5. Potential for human exposure, pp 115 - 129. IN Draft Toxicological Profile for Mercury, October 1992. Contract No. 205-88-0608, Agency for Toxic Substance and Disease Registry, U.S. Dept. of Health and Human Serv., Atlanta, Georgia. 230p.

**DRAFT**

**TOXICOLOGICAL PROFILE FOR  
MERCURY**

Prepared by:

Clement International Corporation  
Under Contract No. 205-88-0608

Prepared for:

**U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES**  
**Public Health Service**  
**Agency for Toxic Substances and Disease Registry**

October 1992

## 5. POTENTIAL FOR HUMAN EXPOSURE

### 5.1 OVERVIEW

Mercury occurs naturally as a mineral and is distributed throughout the environment. The compound has three valence states and is found in the environment in the form of various inorganic and organic complexes and as the elemental metal. The major features of the biogeochemical cycle of mercury include degassing of mineral mercury from the lithosphere and hydrosphere, long-range transport in the atmosphere, wet and dry deposition to land and surface water, sorption to soil and sediment particulates, and bioaccumulation in terrestrial and aquatic food chains.

Inhalation of mercury in workplace atmospheres is the main route of occupational exposure to the compound. The most recent estimate indicates that about 70,000 people are potentially exposed to mercury in workplace environments in the United States. The general population is exposed to mercury primarily through ingestion of contaminated foodstuffs, with fish being the major source of dietary mercury. Populations with potentially high exposures to mercury include workers in industries processing or using the compound and members of the general public who routinely consume large amounts of fish.

Mercury has been identified in 600 of the 1,300 hazardous waste sites on the NPL (HAZDAT 1992). The frequency of these sites can be seen in Figure 5-1. Of these sites, 593 are located in the United States and 7 are located in the Commonwealth of Puerto Rico (not shown).

### 5.2 RELEASES TO THE ENVIRONMENT

Of the estimated 195,460 pounds of elemental mercury released or transferred from industrial facilities reported in the Toxics Release Inventory (TRI) in 1990, 27,339 pounds were released to the environment and 168,079 pounds were transferred off-site by the 39 facilities reporting to the 1990 Toxics Release Inventory (TRI90 1992) (see Table 5-1). A TRI facility is any general manufacturing facility with 10 or more full-time employees that produces, imports, or processes 75,000 or more pounds of any TRI chemical or that uses more than 10,000 pounds of a TRI chemical in a year. The data listed in the TRI should be used with caution because only certain types of facilities are required to report. This is not an exhaustive list.

#### 5.2.1 Air

Mercury is a naturally occurring metal that is ubiquitous in the environment. The compound is released to environmental media by both natural processes and anthropogenic sources. Mercury ore is found in all classes of rocks, including limestone, calcareous shales, sandstone, serpentine, chert, andesite, basalt, and rhyolite. The normal concentration of mercury in igneous and sedimentary rocks and minerals appears to be 10–50 ng/g (Andersson 1979); however, the mineral cinnabar contains 86.2% mercury (Stokinger 1981). The major source of atmospheric mercury has been reported to be global degassing of mineral mercury from the lithosphere and hydrosphere at a rate of 25,000–150,000 metric tons/year (WHO 1976). Anthropogenic releases of mercury to the atmosphere have been estimated to be 2,000–3,000 metric tons/year, mostly from the mining and smelting of mercury ores, industrial processes involving the use of mercury, and combustion of fossil fuels, primarily coal (Lindberg 1984). Mercury emissions from coal-fired power plants are almost exclusively in the vapor phase (98%) (Germani and Zoller 1988). Other potential emission sources include chlorine-alkali manufacturing facilities, copper and zinc smelting operations, paint application, waste oil combustion (EPA 1987f), geothermal energy plants (Baldi 1988), and municipal waste incineration (Bache et al. 1991). Of these, combustion of fossil fuels is the largest source (Gavis and Ferguson 1972). In addition, the incineration of medical waste has been found to release up to 12.3 mg mercury/m<sup>3</sup> (Glasser et al. 1991). Other potential emission sources include slag from metal production, fires at waste deposits, and diffuse emissions from other anthropogenic sources.

## 5. POTENTIAL FOR HUMAN EXPOSURE

FIGURE 5-1. FREQUENCY OF NPL SITES WITH MERCURY CONTAMINATION \*

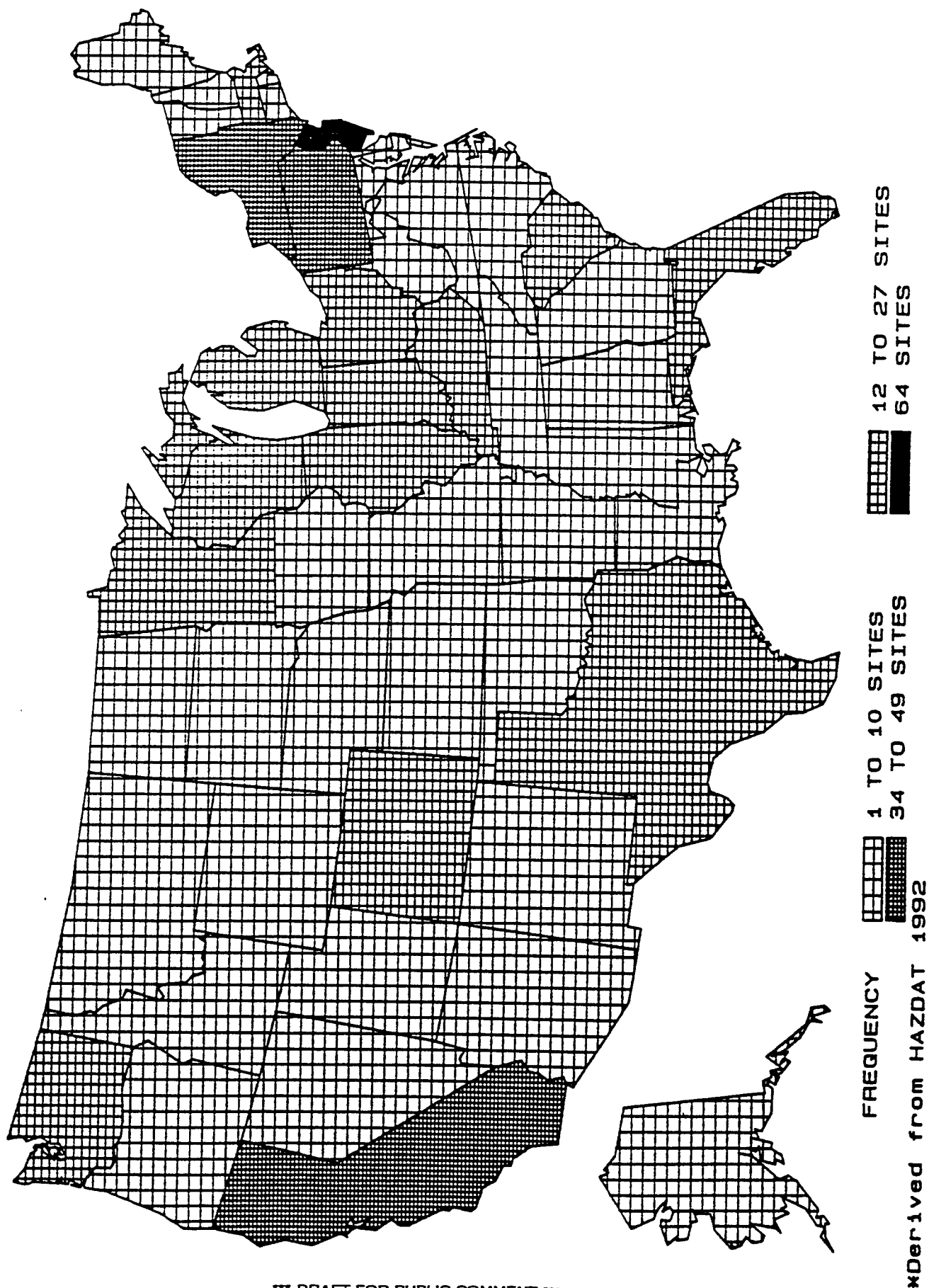


TABLE 5-1. Releases to the Environment from Facilities That Manufacture or Process Elemental Mercury\*

| Facility   | Location <sup>b</sup>             | Reported amounts released in pounds |                       |         |          |                                |                            | Off-site waste transfer |
|--|-----------------------------------|-------------------------------------|-----------------------|---------|----------|--------------------------------|----------------------------|-------------------------|
|  |                                   | Air                                 | Underground Injection | Water   | Land     | Total environment <sup>c</sup> | POTW <sup>d</sup> transfer |                         |
| AKZO CHEMICALS INC.<br>OCCIDENTAL CHEMICAL CORP. | AXIS, AL<br>MOBILE, AL            | 1,500<br>537                        | 0<br>0                | 5<br>11 | 250<br>0 | 1,755<br>548                   | 0<br>0                     | 6,500<br>6,100          |
| OCCIDENTAL CHEMICAL CORP.                        | SHEFFIELD, AL                     | 123                                 | 0                     | 53      | 0        | 176                            | 0                          | 16,400                  |
| OCCIDENTAL CHEMICAL CORP.                        | DELAWARE CITY, DE                 | 357                                 | 0                     | 16      | 0        | 373                            | 0                          | 8,112                   |
| OLIN CORP. AUGUSTA PLANT                         | AUGUSTA, GA                       | 1,317                               | 0                     | 14      | 0        | 1,331                          | 0                          | 4,730                   |
| LCP CHEMICALS GEORGIA                            | BRUNSWICK, GA                     | 1,296                               | 0                     | 13      | 0        | 1,309                          | 0                          | 250                     |
| MAGNETROL INT. INC.                              | DOWNERS GROVE, IL                 | 5                                   | 0                     | 0       | 0        | 5                              | 0                          | 0                       |
| HONEYWELL INC. MICRO SWITCH DIV.                 | FREEDPORT, IL                     | 4                                   | 0                     | 0       | 0        | 4                              | 0                          | 0                       |
| DURAKOOL INC.                                    | ELKHART, IN                       | 5                                   | 0                     | 0       | 0        | 5                              | 0                          | 1,420                   |
| HERMASEAL CO.                                    | ELKHART, IN                       | 5                                   | 0                     | 0       | 0        | 5                              | 0                          | 42,701                  |
| BF GOODRICH CO. BFG INTERMEDIATES CO. INC.       | CALVERT CITY, KY                  | 1,200                               | 0                     | 17      | 0        | 1,217                          | 0                          | 12,000                  |
| PIONEER CHLOR ALKALI CO. INC.                    | SAINT GABRIEL, LA                 | 1,286                               | 0                     | 17      | 0        | 1,303                          | 0                          | 25,139                  |
| PPG INDUSTRIES INC.                              | WESTLAKE, LA                      | 1,212                               | 0                     | 12      | 0        | 1,224                          | 0                          | 24,800                  |
| LCP CHEMICALS MAINE                              | ORRINGTON, ME                     | 1,015                               | 0                     | 6       | 1        | 1,022                          | 0                          | 543                     |
| ELM PLATING CO.                                  | JACKSON, MI                       | 5                                   | 0                     | 0       | 0        | 5                              | 5                          | 5                       |
| KERR MANUFACTURING CO.                           | ROMULUS, MI                       | 0                                   | 0                     | 0       | 0        | 0                              | 0                          | 0                       |
| EVEREADY BATTERY CO. INC.                        | MARYVILLE, MO                     | 30                                  | 0                     | 0       | 0        | 30                             | 0                          | 80                      |
| STENNIS SPACE CENTER EVEREADY BATTERY CO. INC.   | STENNIS SPACE, MS<br>ASHEBORO, NC | 250<br>5                            | 0<br>0                | 0<br>2  | 0<br>0   | 250<br>7                       | 0<br>1                     | 250<br>27               |
| DURACELL USA                                     | LEXINGTON, NC                     | 7                                   | 0                     | 0       | 0        | 7                              | 1                          | 559                     |
| LCP CHEMICALS N.C.                               | RIEGELWOOD, NC                    | 1,095                               | 0                     | 2       | 0        | 1,097                          | 0                          | 109                     |
| COSAN CHEMICAL CORP.                             | CARLSTADT, NJ                     | 39                                  | 0                     | 1       | 0        | 40                             | 5                          | 11                      |
| CHIATAS GLASS CO.                                | VINELAND, NJ                      | 0                                   | 0                     | 0       | 0        | 0                              | 0                          | 0                       |
| MERCURY REFINING CO. INC.                        | ALBANY, NY                        | 500                                 | 0                     | 0       | 0        | 500                            | 0                          | 12                      |
| OCCIDENTAL CHEMICAL CORP. NIAGARA PLANT          | NIAGARA FALLS, NY                 | 34                                  | 0                     | 0       | 0        | 34                             | 5                          | 3,070                   |
| OLIN CHEMICALS                                   | NIAGARA FALLS, NY                 | 1,394                               | 0                     | 3       | 0        | 1,397                          | 15                         | 6,367                   |
| LCP CHEMICALS - NY                               | SOLVAY, NY                        | 25                                  | 0                     | 0       | 0        | 25                             | 0                          | 350                     |
| LINCHEM. INC.                                    | ASHTABULA, OH                     | 1,796                               | 0                     | 6       | 2        | 1,804                          | 0                          | 0                       |

## 5. POTENTIAL FOR HUMAN EXPOSURE

TABLE 5-1. Releases to the Environment from Facilities That Manufacture or Process Elemental Mercury (Continued)

| Facility                              | Location <sup>b</sup> | Reported amounts released in pounds |                       |       |       |                                |                            | Off-site waste transfer |
|---------------------------------------|-----------------------|-------------------------------------|-----------------------|-------|-------|--------------------------------|----------------------------|-------------------------|
|                                       |                       | Air                                 | Underground Injection | Water | Land  | Total environment <sup>c</sup> | POTW <sup>d</sup> transfer |                         |
| GE CO. BUCYRUS LAMP PLANT             | BUCYRUS, OH           | 1,750                               | 0                     | 0     | 0     | 1,750                          | 0                          | 2,772                   |
| BETHLEHEM APPARATUS CO. INC.          | HELLERTOWN, PA        | 5                                   | 0                     | 0     | 5     | 10                             | 5                          | 5                       |
| ZINC CORP. OF AMERICA                 | MONACA, PA            | 0                                   | 0                     | 0     | 0     | 0                              | 0                          | 0                       |
| EMERSON PUERTO RICO INC.              | DORADO, PR            | 0                                   | 0                     | 0     | 0     | 0                              | 0                          | 250                     |
| OLIN CORP. CHARLESTON FACILITY        | CHARLESTON, TN        | 1,285                               | 0                     | 25    | 3,926 | 5,236                          | 0                          | 5                       |
| VALERO REFINING CO.                   | CORPUS CHRISTI, TX    | 0                                   | 0                     | 0     | 0     | 0                              | 0                          | 2                       |
| GEORGIA-PACIFIC CORP. BELLINGHAM DIV. | BELLINGHAM, WA        | 1,250                               | 0                     | 250   | 0     | 1,500                          | 0                          | 4,050                   |
| SEATTLE STEEL INC.                    | SEATTLE, WA           | 500                                 | 0                     | 0     | 0     | 500                            | 0                          | 0                       |
| RAYOVAC CORP. FENNINGORE PLANT        | FENNINGORE, WI        | 10                                  | 0                     | 0     | 0     | 10                             | 5                          | 250                     |
| HANLIN CHEMICALS WEST VIRGINIA INC.   | MOUNDSVILLE, WV       | 1,312                               | 0                     | 48    | 0     | 1,360                          | 0                          | 960                     |
| PPG INDUSTRIES INC.                   | NEW MARTINSVILLE, WV  | 1,250                               | 0                     | 250   | 0     | 1,500                          | 0                          | 250                     |
| Totals                                |                       | 22,404                              | 0                     | 751   | 4,184 | 27,339                         | 42                         | 168,079                 |

<sup>b</sup>Derived from TRI90 (1992)<sup>c</sup>Post Office state abbreviations<sup>d</sup>The sum of all releases of the chemical to air, land, water, and underground injection wells by a given facility.<sup>e</sup>POTW = publicly owned treatment works



such as dentists and industrial activities. Point source emissions may be reduced by controls on waste incineration (Lindqvist 1991b).

Of the 27,339 pounds of mercury released to the environment from TRI facilities in 1989, 22,404 pounds were air emissions from 34 facilities (see Table 5-2) (TRI90 1992).

### 5.2.2 Water

Weathering of mercury-bearing minerals in igneous rocks releases about 800 metric tons of mercury per year to surface waters on a global basis (Gavis and Ferguson 1972). Mercury may also be released to surface waters in effluents from a number of industrial processes including chlorine-alkali production, mining operations and ore processing, metallurgy and electroplating, chemical manufacturing, ink manufacturing, paper mills, leather tanning, pharmaceutical production, and textile manufacture (Dean et al. 1972; EPA 1971c). The compound has been detected at approximately 4 µg/L in residential and commercial wastewater effluents (Levins et al. 1979), although discharges from a regional wastewater treatment facility on the St. Louis River that received primarily municipal wastes contained 364 ng/L of mercury and resulted in concentrations in the adjacent sediment of up to 5,070 ng/g (Glass et al. 1990).

Of the 27,339 pounds of mercury released to the environment from TRI facilities in 1990, 751 pounds were released to water from 19 facilities (see Table 5-2) (TRI90 1992).

### 5.2.3 Soil

Mercury is released to cultivated soils through the direct application of inorganic and organic fertilizers (e.g., sewage sludge and compost), lime, and fungicides containing the compound (Andersson 1979). Additional anthropogenic releases are expected through the disposal of industrial and domestic products (e.g., thermometers, electrical switches, and batteries) as solid wastes in landfills.

Of the 27,339 pounds of mercury released to the environment from TRI facilities in 1990, 4,184 pounds were released on-site to land from five facilities (see Table 5-2) (TRI90 1992).

## 5.3 ENVIRONMENTAL FATE

### 5.3.1 Transport and Partitioning

The global biogeochemical cycling of mercury is characterized by degassing of the element from soils and surface waters, followed by atmospheric transport, deposition of mercury back to land and surface waters, and sorption of the compound to soil or sediment particulates. Particulate-bound mercury can be converted to insoluble mercury sulfide and precipitated or bioconverted into more volatile or soluble forms that re-enter the atmosphere or are taken up by biota and bioaccumulated in terrestrial and aquatic food chains (EPA 1984b).

Mercury has three valence states. The specific state and form in which the compound is found in an environmental medium is dependent upon a number of factors, including the redox potential and pH of the medium. The most reduced form is metallic mercury, which is a liquid at ambient temperatures but readily vaporizes. Elemental mercury is the principal form of the compound in the atmosphere, and therefore the form involved in long-range transport of the compound. In soils and surface waters, mercury can exist in the mercuric ( $\text{Hg}^{+2}$ ) and mercurous ( $\text{Hg}^{+1}$ ) states as a number of complex ions with varying water solubilities. Mercuric mercury, present as complexes and chelates with ligands, is probably the predominant form of mercury present in surface waters.

Metallic mercury released in vapor form to the atmosphere can be transported long distances before wet and dry deposition processes return the compound to land and water surfaces. Residence time in the

## 5. POTENTIAL FOR HUMAN EXPOSURE

atmosphere has been estimated to range from 6–90 days (Andren and Nriagu 1979) to 0.3–2.0 years (EPA 1984b). Although local sources are important, a 72-hour travel time trajectory for mercury indicates that sources up to 2,500 km distant may account for mercury deposition from precipitation (Glass et al. 1991). The atmosphere is the smallest environmental reservoir for mercury, containing only about 1,000 metric tons (NAS 1977). Most inert mercury ( $\text{Hg}^{+2}$ ) in precipitation is bound to aerosol particulates, which are relatively immobile when deposited on soil or water (Meili et al. 1991). Mercury is also present in the atmosphere to a limited extent in unidentified soluble forms associated with particulate matter. In addition to wet and dry deposition processes, mercury may also be removed from the atmosphere by sorption of the vapor form to soil or water surfaces (EPA 1984b). Wet deposition is the primary method of removal of mercury from the atmosphere (approximately 66%) (Lindqvist 1991b; Fitzgerald et al. 1991) and may account for the mercury content in most lakes that do not receive inputs from other sources, e.g., industrial effluents (Hurley et al. 1991).

The transport and partitioning of mercury in surface waters and soils is influenced by the particular form of the compound. More than 97% of the dissolved gaseous mercury found in water consists of elemental mercury (Vandal et al. 1991). Volatile forms (e.g., metallic mercury and dimethylmercury) are expected to evaporate to the atmosphere, whereas solid forms partition to particulates in the soil or water column, and in the water column are transported downward to the sediments (Hurley et al. 1991). Vapor-phase mercury volatilized from surface waters has been measured (Schroeder and Fanaki 1988); however, the dominant process controlling the distribution of mercury compounds in the environment appears to be the sorption of nonvolatile forms to soil and sediment particulates. In the St. Lawrence River, the total dissolved mercury concentration was 12 mg/L, of which 70% was associated with organic matter. The removal mechanism is flocculation of organic mercury colloids in fresh water (Cossa et al. 1988). The sorption process has been found to be related to the organic matter content of the soil or sediment; the pH of the medium apparently does not affect the process. Mercury is strongly sorbed to humic materials and sesquioxides in soil at a pH higher than 4 (Blume and Brummer 1991) and to the surface layer of peat (Lodenius and Autio 1989). Mercury is sorbed to lateritic soil up to a maximum loading capacity of 15 g/kg (Ahmad and Qureshi 1989). Inorganic mercury sorbed to particulate material is not readily desorbed; thus, freshwater and marine sediments are important repositories for inorganic forms of the compound, and leaching is a relatively insignificant transport process in soils. However, surface runoff is an important mechanism for moving mercury from soil to water, particularly for soils with high humic content (Meili 1991). Mobilization of sorbed mercury from particulates can occur through chemical or biological reduction to elemental mercury and bioconversion to volatile organic forms (Andersson 1979; Callahan et al. 1979; EPA 1984b). Adsorption of mercury in soil is decreased with increasing pH and/or chloride ion concentrations (Schuster 1991). Metallic mercury may move through the top 3–4 cm of dry soil at atmospheric pressure; however, it is unlikely that further penetration would occur (Eichholz et al. 1988).

The most common organic form of mercury, methylmercury, is soluble, mobile, and quickly enters aquatic food chain. Methylmercury in surface waters is rapidly accumulated by aquatic organisms; concentrations in carnivorous fish at the tops of freshwater and salt water food chains (e.g., pike, tuna, and swordfish) are biomagnified on the order of 10,000–100,000 times the concentrations found in ambient waters (Callahan et al. 1979; EPA 1980a, 1984b). The biological half-life of methylmercury in mussels is estimated to be 1,000 days, although this form of mercury is accumulated to a greater extent in biological tissue than are inorganic forms of mercury (Cossa 1989; Riisgard and Hansen 1990). The biomagnification of mercury has been demonstrated by the elevated levels found in piscivorous fish, compared with fish lower down the food chain (Jackson 1991; Kohler et al. 1990). Biomagnification factors for mercury in the food webs of Lakes Michigan and Ontario were lowest for amphipods feeding on mysids (1.1) and highest for fish feeding on plankton (10.4–11.8) (Evans et al. 1991). Aquatic macrophytes also have been found to bioconcentrate methylmercury (Ribeyre 1991). Bioaccumulation of methylmercury in aquatic food chains is of interest because it is generally the most important source of nonoccupational human exposure to the compound (EPA 1984b). Aquatic plants have been found to bioaccumulate mercury in almost direct proportion to the mercury concentration in the water (Ribeyre et al. 1991).

The potential for bioaccumulation in terrestrial food chains is demonstrated by the uptake of mercury by the edible mushroom *Pleurotus ostreatus*, grown on compost containing mercury up to concentrations of 0.2 mg/kg. The bioaccumulation factor was 65–140, indicating that there are risks to human health if these mushrooms are eaten (Bressa et al. 1988); however, other data indicate that virtually no mercury is taken up from the soil into the shoots of plants such as peas, although mercury concentrations in the roots may be significantly elevated and reflect the mercury concentrations of the surrounding soil (Lindqvist 1991b).

### 5.3.2 Transformation and Degradation

Mercury is transformed in the environment by biotic and abiotic oxidation and reduction, bioconversion of organic and inorganic forms, and photolysis of organomercurials. Mercury forms stable complexes with organic compounds. Monoalkyl mercury compounds are relatively soluble (e.g., methylmercuric chloride); however, the solubility of methylmercury is decreased with increasing dissolved organic carbon content, indicating that it is bound by organic matter in water (Miskimmin 1991). Dialkyl mercury compounds are relatively insoluble (e.g., dimethylmercury) (Callahan et al. 1979; EPA 1984b); however, dimethylmercury is volatile, although it makes up less than 3% of the dissolved gaseous mercury found in water (Andersson et al. 1990; Vandal et al. 1991).

Inorganic mercury can be methylated by microorganisms indigenous to soils, fresh water, and salt water. This process is mediated by various microbial populations under both aerobic and anaerobic conditions. The most probable mechanism for this reaction involves the nonenzymatic methylation of mercuric mercury ions by methylcobalamine compounds produced as a result of bacterial synthesis.

#### 5.3.2.1 Air

The main transformation process for mercury compounds in the atmosphere appears to be photolysis of organomercurials (EPA 1984b; Johnson and Bramen 1974; Williston 1968). Metallic mercury vapor may also be oxidized to other forms in the removal of the compound from the atmosphere by precipitation (EPA 1980a). The oxidation/reduction of mercury with dissolved ozone, hydrogen peroxide, hypochlorite entities, or organoperoxy compounds or radicals may also occur in the atmosphere (Schroeder et al. 1991). The overall residence time of elemental mercury in the atmosphere has been estimated to be 6–24 months, although in clouds a fast oxidation reaction on the order of hours may occur between elemental mercury and ozone. Some mercury compounds, such as mercuric sulfide, are quite stable in the atmosphere as a result of their binding to particles in the aerosol phase (Lindqvist 1991b).

#### 5.3.2.2 Water

The most important transformation process in the environmental fate of mercury in surface waters is biotransformation. Photolysis of organomercurials may also occur in surface waters, but the significance of this process in relation to biotransformation is not clear (Callahan et al. 1979).

Any form of mercury entering surface waters can be microbially converted to methylmercuric ion given favorable conditions. Sulfur-reducing bacteria are responsible for most of the mercury methylation in the environment (Gilmour and Henry 1991), with anaerobic conditions favoring their activity (Regnell and Tunlid 1991). Yeast, such as *Candida albicans* and *Saccharomyces cerevisiae* whose growth is favored by low pH conditions, are able to methylate mercury and are also able to reduce ionic mercury to elemental mercury (Yannai et al. 1991). Methyl cobalamine compounds, produced by bacterial synthesis, appear to be involved in the nonenzymatic methylation of inorganic mercury ions (Regnell and Tunlid 1991). The rate of methylmercury formation is largely determined by the concentration of methyl cobalamine compounds, inorganic mercuric ion, and the oxygen concentration of the water, with the rate increasing as the conditions become anaerobic. Volatile elemental mercury may be formed through the demethylation of methylmercury or the reduction of inorganic mercury, with anaerobic conditions favoring the

## 5. POTENTIAL FOR HUMAN EXPOSURE

demethylation of methylmercury or the reduction of inorganic mercury, with anaerobic conditions favoring the demethylation of the methylmercury (Barkay et al. 1989; Callahan et al. 1979; Regnell and Tunlid 1991). Increased dissolved organic carbon levels reduce methylation of mercury in the water column (Gilmour and Henry 1991). Alternatively, low pH favors the methylation of mercury in the water column, particularly in acid deposition lakes, while inhibiting its demethylation (Gilmour and Henry 1991). It has also been shown that the methylation rate is not affected by addition of sulfate in typical softwater lakes (Kerry et al. 1991). At a pH of 4–9, and a normal sulfide concentration, mercury will form mercury sulfide, which precipitates out and removes mercury ions from the water, reducing the availability of mercury to fish. Under acidic conditions, however, the activity of the sulfide ion decreases, thus inhibiting the formation of mercury sulfide and favoring the formation of methylmercury (Bjornberg et al. 1988). Low pH and high mercury sediment concentrations favor the formation of methylmercury, which has greater bioavailability potential for aquatic organisms than inorganic mercury compounds. Methylmercury may be ingested by aquatic organisms such as yellow perch, which is in turn consumed by piscivorous fish in aquatic food chains (Cope et al. 1990; Wiener et al. 1990). Mercury cycling occurs in freshwater lakes with surface waters with the concentrations and speciation of the mercury being dependent on limnological features and water stratification. Surface waters may be saturated with volatile elemental mercury, with sediments being the primary source of the mercury. During the summer months, surface concentrations of methyl and elemental mercury decline although they remain relatively constant in deeper waters (Bloom and Effler 1990).

Abiotic reduction of mercuric mercury to metallic mercury in aqueous systems can also occur, particularly in the presence of soluble humic substances, i.e., acidic waters containing humic and fulvic acids. This reduction process is enhanced by light, occurs under both aerobic and anaerobic conditions, and is inhibited by the competition from chloride ions (Allard and Arsenie 1991).

### 5.3.2.3 Sediment and Soil

Mercury compounds in soils may undergo the same chemical and biological transformations described for surface waters. Mercuric mercury usually forms various complexes with chloride and hydroxide ions in soils, the specific complexes formed being dependent on the pH, salt content, and composition of the soil solution. Formation and degradation of organic mercurials in soils appear to be mediated by the same types of microbial processes occurring in surface waters, and may also occur through abiotic processes (Andersson 1979). Elevated levels of chloride ions reduces methylation of mercury in river sediments, sludge, and soil (Olson et al. 1991), although increased levels of organic carbon and sulfate ions increase methylation in sediments (Gilmour and Henry 1991). In freshwater ecosystems, the presence of chloride ions (0.02 Molar [M]) may accelerate the release of mercury from sediments; a similar phenomenon has been observed in estuarine ecosystems (Wang et al. 1991).

Mercury, frequently present in mine tailings, was toxic to bacteria isolated from a marsh treatment system used to treat municipal waste waters. The minimum concentration that inhibited the bacteria (as determined by intracellular ATP levels) was approximately  $0.07 \pm 0.15$  mg/L (Desjardins et al. 1988).

## 5.4 LEVELS MONITORED OR ESTIMATED IN THE ENVIRONMENT

### 5.4.1 Air

Ambient air concentrations of mercury have been reported to average approximately 10–20 ng/m<sup>3</sup>, with higher concentrations in industrialized areas (EPA 1980a). Higher levels (10–15 µg/m<sup>3</sup>) have been detected near point emission sources such as mercury mines and refineries and agricultural fields treated with mercury fungicides. However, concentrations in ambient air are unlikely to exceed an average value of 50 ng/m<sup>3</sup> (EPA 1980a, 1984b). Atmospheric concentrations of mercury over lakes in Wisconsin averaged 2.0 ng/m<sup>3</sup> (Wiener et al. 1990) and ranged from 6.3 ng/m<sup>3</sup> to 16.0 ng/m<sup>3</sup> above the water surface of the mercury-contaminated Wabigoon River in Ontario (Schroeder and Fanaki 1988).

### 5.4.2 Water

Concentrations in rainwater and fresh snow are generally below  $0.2 \mu\text{g/L}$  (EPA 1980a, 1984b). The background level of mercury in precipitation has been estimated to be approximately  $0.0032\text{--}0.0152 \mu\text{g/m}^3$  (Fitzgerald et al. 1991), although mercury concentrations in precipitation collected in Minnesota during 1988 and 1989 averaged  $0.018 \mu\text{g/L}$  for an average annual deposition of  $15 \mu\text{g/m}^2$  (Glass et al. 1991). Antarctic surface snow contained a mean mercury concentration of less than  $1 \text{ pg/g}$  (Dick et al. 1990). Fresh waters without known sources of mercury contamination generally contain less than  $5 \text{ ng/L}$  of total mercury in aerobic surface waters (Gilmour and Henry 1991). Mercury present in precipitation at an average concentration of  $10 \text{ ng/L}$  may account for more than half of the mercury inputs to surface waters near Dorset, Ontario, compared with stream runoff suggesting that atmospheric deposition is a significant source of mercury in surface waters (Mierle 1990).

Surface waters of rural Wisconsin lakes contained  $4.7\text{--}9.7 \text{ pM}$  concentrations of total mercury (Fitzgerald and Watras 1989). Similar levels were seen in the St. Louis River estuary where mercury levels in precipitation averaged  $22 \text{ ng/L}$ , although ambient air levels averaged  $3 \text{ ng/m}^3$ . Mercury levels in water-borne particulates in the river ranged from  $18$  to  $500 \text{ ng/L}$  (Glass et al. 1990). Water samples from lakes and rivers in the Ottawa, Ontario, region of Canada had total mercury concentrations of  $3.5\text{--}11.4 \text{ ng/L}$  with organic mercury constituting  $22\text{--}37\%$  of the total mercury (Schintu et al. 1989). Mercury was detected in Crab Orchard Lake, Illinois, water samples at  $0.07\text{--}0.281 \mu\text{g/L}$  (Kohler et al. 1990). Total mercury concentrations in surface waters of California lakes and rivers ranged from  $2.4$  to  $520 \text{ pM}$  with the dissolved particulate fraction being dominant ( $89\%$ ;  $2\text{--}60 \text{ pM}$ ) (Gill and Bruland 1990).

The baseline concentration of mercury in unpolluted marine waters has been estimated to be  $0.005\text{--}0.006 \mu\text{g/L}$  (Matsunaga et al. 1979),  $59 \text{ ng/L}$  (total dissolved and particulate mercury) (Fitzgerald 1979), and less than  $2 \text{ ng/L}$  (Fowler 1990). Sediments taken from coastal areas off British Columbia, Canada, contained variable concentrations of mercury ranging from  $0.05 \mu\text{g/g}$  to  $0.20 \mu\text{g/g}$ , with slightly higher mercury concentrations in the muscle of fish taken from the same waters; bioconcentration factors ranged from less than  $1$  to  $14$  (Harding and Goyette 1989). Sediment samples analyzed for NOAA's National Status and Trends Program between 1984 and 1987, showed that  $38$  of  $175$  sites contained mercury concentrations in excess of  $0.41 \mu\text{g/g}$ , the level considered to be indicative of sediment toxicity (O'Connor and Ehler 1991).

Concentrations in estuarine waters have been reported to range from  $0.002$  to  $0.45 \mu\text{g/L}$  (total dissolved and particulate mercury) (Fitzgerald 1979). The New York Bight was found to contain dissolved mercury concentrations in the range of  $10\text{--}90 \text{ ng/L}$  (Fowler 1990).

Mercury has been found at levels greater than  $0.5 \mu\text{g/L}$  in  $15\text{--}30\%$  of wells tested in ground water surveys (EPA 1985c). Drinking water is generally assumed to contain less than  $0.025 \mu\text{g/L}$  (EPA 1984b).

### 5.4.3 Sediment and Soil

Flocculent and hydrous sediments from lakes in Wisconsin contained the highest levels of mercury in the top  $15 \text{ cm}$  with concentrations ranging from  $0.09$  to  $0.24 \mu\text{g/g}$ . Lower levels contained significantly less ( $0.04\text{--}0.07 \mu\text{g/g}$ ). Because the lakes are not known to receive any direct deposition of mercury, it was postulated that atmospheric deposition was the primary source (Rada et al. 1989). Mercury levels in surface sediments of the St. Louis River ranged from  $18$  to  $500 \text{ ng/L}$  (Glass et al. 1990). Mercury was detected in sediment samples from Crab Orchard Lake, Illinois, at greater than  $60 \mu\text{g/L}$  (Kohler et al. 1990). Surficial sediment samples from Lake St. Clair in Canada had mercury concentrations ranging from  $<0.025$  to  $1.2 \mu\text{g/g}$ . Mercury concentrations were correlated with particle size fractions and organic matter content (Mudroch and Hill 1989). Mercury concentrations in sediments taken from lakes adjacent to coal-fired power plants near Houston, Texas, ranged from  $255$  to  $360 \text{ mg/L}$  in the summer and from  $190$  to  $279 \text{ mg/L}$  in the winter up to a depth of  $28 \text{ cm}$  (Wilson and Mitchell 1991). Surficial sediment samples

## 5. POTENTIAL FOR HUMAN EXPOSURE

from the Lake Roosevelt/Upper Columbia River in Washington State contained up to 2.7  $\mu\text{g/g}$  mercury (Johnson et al. 1990), whereas surficial sediments taken from Canadian lakes receiving atmospheric input from smelters contained between 0.03 and 9.22  $\mu\text{g/g}$  mercury with the highest values being found in lakes nearest the smelters. Sediment concentrations were not correlated with mercury concentrations in fish taken from the Canadian lakes; these latter concentrations ranged from 0.003 to 0.88  $\mu\text{g/g}$  with the highest concentration found in fish from one of the least contaminated lakes (Harrison and Klaverkamp 1990).

In a review of the mercury content of virgin and cultivated surface soils from a number of countries, it was found that the average concentrations ranged from 20 to 625 ng/g (Andersson 1979). The highest concentrations were generally found in soils from urban locations and in organic versus mineral soils. The mercury content of most soils varies with depth, with the highest concentrations generally found in the surface layers.

## 5.4.4 Other Environmental Media

Surveys conducted in the United States by the National Academy of Sciences, the Food and Drug Administration, and the Department of Commerce indicate that dietary consumption of fish is the most important source of exposure of the general population to mercury. Mercury concentrations in most non-fish foodstuffs are generally less than 0.02  $\mu\text{g/g}$ , although concentrations of up to 0.2  $\mu\text{g/g}$  have been detected in meat and poultry (NAS 1977).

The average concentration of mercury in most fish is less than 0.2  $\mu\text{g/g}$ ; average mercury concentrations in fish gathered nationwide as part of the National Contaminant Biomonitoring Program conducted in 1984–1985 were 0.10  $\mu\text{g/g}$  and showed no decline from 1981 levels (Schmitt and Brumbaugh 1990). However, concentrations in large carnivorous freshwater (e.g., pike) and marine (e.g., swordfish) fish have been found to exceed 1  $\mu\text{g/g}$  (EPA 1980a, 1984b); fish taken from the Savannah River contained between 0.10 and 0.72  $\mu\text{g/g}$  mercury (Winger et al. 1990). Samples of zooplankton from an Illinois lake contained approximately 10 ng/g mercury. Analysis of fish taken from the lake in 1986 indicated whole body mercury concentrations ranging from 11.6  $\mu\text{g/kg}$  in inedible shad to 69  $\mu\text{g/kg}$  in edible largemouth bass; older fish generally had higher mercury concentrations (Kohler et al. 1990). Methylmercury makes up over 99% of the total mercury detected in fish muscle tissue with no detection of inorganic or dimethylmercury (Grieb et al. 1990). Mercury levels were examined in aquatic organisms taken from the Calcasieu River/Lake Complex in Louisiana. The order of enrichment was as follows: shrimp (0.2  $\mu\text{g/g}$ ) < mussel (0.3  $\mu\text{g/g}$ ) < fish (0.4  $\mu\text{g/g}$ ) = oyster (0.4  $\mu\text{g/g}$ ) < zooplankton (1.4  $\mu\text{g/g}$ ) (Ramelow et al. 1989). Oysters (*Crassostrea virginica*) collected around the Gulf of Mexico between 1986 and 1989 had mercury concentrations ranging from <0.01 to 0.72  $\mu\text{g/g}$  (mean 0.127  $\mu\text{g/g}$ ) (Presley et al. 1990). Oysters taken from the Mississippi Sound in 1986 generally did not contain mercury at levels exceeding the level of detection (0.02  $\mu\text{g/g}$ ), two samples had detectable mercury at 0.66 and 6.6  $\mu\text{g/g}$  (Lytle and Lytle 1990). Average mercury concentrations for aquatic organisms collected from the Wabigoon/English/Winnipeg River system in Canada were as follows: 0.06–2.2  $\mu\text{g/g}$  for crayfish, 0.01–0.55  $\mu\text{g/g}$  for perch, and 0.04–1.2  $\mu\text{g/g}$  for pike. Mercury concentrations were found to increase with distance from the pollutant source, possibly as a result of the increased bioavailability of organic mercury produced by aquatic microorganisms (Parks et al. 1991). Crayfish taken from 13 Ontario lakes without known mercury sources contained mercury concentrations ranging from 0.02 to 0.64  $\mu\text{g/g}$ ; the concentrations were positively correlated with organism weight and fish mercury concentrations (Allard and Stokes 1989). Brown trout taken from Lake Ontario contained between 0.18–0.21  $\mu\text{g/g}$  mercury in unskinned fillets and between 0.24–0.26  $\mu\text{g/g}$  mercury in skinned fillets, indicating that methylmercury is associated with the protein fraction of fish tissue (Gutenmann and Lisk 1991).

Background mercury concentrations in freshwater plants from uncontaminated waters, which often constitute the bottom of the aquatic food chain, contained an average concentration of 4.1  $\mu\text{g/g}$ , whereas the maximum mercury concentration in plants taken from polluted waters was 19  $\mu\text{g/g}$  with methylmercury being retained longer than inorganic mercury (Outridge and Noller 1991). Grasses sampled downwind of a

municipal waste incinerator contained up to 0.20  $\mu\text{g/g}$  of mercury with concentrations decreasing with distance from the facility (Bache et al. 1991). Background mercury levels in vegetation are usually below 0.1  $\mu\text{g/g}$  dry weight (Lindqvist 1991f). An analysis of finger paints and make-up paints manufactured in Europe showed that they all contained less than 1 ppm mercury (Rastogi 1992).

## 5.5 GENERAL POPULATION AND OCCUPATIONAL EXPOSURE

Potential sources of general population exposure to mercury include inhalation of the compound in ambient air, ingestion of contaminated water and foodstuffs, and dental and medical treatments (NIOSH 1973). Dental amalgams are 50% mercury metal by weight (Huggins 1983). EPA (1984b) reported that dietary intake is the most important source of nonoccupational human exposure to mercury, with fish and fish products being the dominant sources of mercury in the diet. Other potential sources of dietary exposure to methylmercury are the consumption of game birds in areas where methylmercury pesticides have been used, and consumption of fish eating birds and mammals or the eggs of fish-eating birds (WHO 1976).

The FDA's total diet study (April 1982–April 1984) estimated an average daily intake of mercury (total) based on measured levels and assumed trace amounts in food representative of the "total diet" of the U.S. population (Gunderson 1988). The estimated daily intake of mercury ranged from 0.49  $\mu\text{g/day}$  for infants aged 6–11 months to 3.9  $\mu\text{g/day}$  for males 25–30 years of age. The average daily intake for females aged 25–30 years was 2.9  $\mu\text{g/day}$ . Expressed as a per weight value, the intake for all age groups except 2-year-old children was approximately 50 ng/kg/day (Clarkson 1990a). For 2-year-old children, the intake was approximately 100 ng/kg/day.

The National Occupational Hazard Survey (NOHS), conducted by the National Institute for Occupational Safety and Health (NIOSH) from 1972 to 1974, estimated that 24,358 workers in 3,255 workplaces were potentially exposed to mercury in the workplace in 1970 (NIOSH 1976). These estimates were derived from observations of the actual use of mercury (73% of total estimate) and the use of generic products suspected of containing the compound (26%). The largest numbers of exposed workers were in the medical and other health services, chemicals and allied products, primary metal, fabricated metal products, electrical equipment and supplies, automotive dealers, service stations, and general building contractor industries. The occupational groups with the largest numbers of exposed workers were clinical laboratory technologists and technicians, machine operators, stock handlers, grinding machine operators, automobile body repairmen, and miscellaneous mechanics and repairmen.

Data from a second workplace survey, the National Occupational Exposure Survey (NOES), conducted by NIOSH from 1980 to 1983, indicated that 67,551 workers, including 21,153 women, in 2,877 workplaces were potentially exposed to mercury in the workplace in 1980 (NIOSH 1984b). Most of the exposed workers were employed in the health services, business services, special trade contractors, and chemical and allied products industries as chemical technicians, science technicians, registered nurses, and machine operators. These estimates were derived from observations of the actual use of mercury (97% of total estimate) and the use of trade-name products known to contain the compound (3%).

Workplace environments presenting the largest potential sources of occupational exposure to mercury include chlorine-alkali production facilities, cinnabar mining and processing operations, and the manufacture and use of instruments containing liquid mercury (Stokinger 1981).

According to NIOSH (1973), the principal route of occupational exposure to mercury is vapor phase inhalation from workplace atmospheres. It should be noted that exposure to mercury may result from mercury transported to the home on clothes of occupationally exposed individuals. In an exposure study for families of workers at a chlor-alkali plant in Charleston, Tennessee, home air levels of mercury averaged 0.92  $\mu\text{g/m}^3$  (ATSDR 1990).

## 5. POTENTIAL FOR HUMAN EXPOSURE

Mercury has been detected in workplace atmospheres at concentrations ranging from 0.16 to 4.89 mg/m<sup>3</sup> in a mining operation (Ladd et al. 1966), from 0.3 to  $\geq 1.2$  mg/m<sup>3</sup> in a milling operation (West and Lim 1968), and at an average TWA concentration of 0.065 mg/m<sup>3</sup> in 21 chlorine-alkali production facilities in the United States and Canada (Smith et al. 1970). Personal air sampling of workers in a recycling plant in Germany detected mercury levels ranging from 115 to 454  $\mu\text{g}/\text{m}^3$  (Schaller et al. 1991).

Human biological media that are routinely monitored as evidence of exposure to mercury include urine, blood, and hair. Urine is most frequently monitored as an indicator of human body burden following chronic exposure to mercury vapor (EPA 1984b). The range of total mercury content of human urine for individuals with no known exposure to mercury has been reported to be 1.0–25.0  $\mu\text{g}/\text{L}$  (Goldwater and Stopford 1977); approximately 95% of all urine samples contain less than 20  $\mu\text{g}$  mercury/L (EPA 1984b). Average urine mercury concentrations of 9–700  $\mu\text{g}/\text{L}$  were reported in 75 workers employed in 13 scientific glassware manufacturing facilities where mercury was used to calibrate the glassware products (Danzinger and Possick 1973). A comparison of mercury content in the urine of Swedish workers exposed to high levels of mercury, dentists, occupationally unexposed workers, and unexposed workers without dental amalgams gave values of 15, 1.7, 0.8, and 0.3  $\mu\text{mol}/\text{mol}$  creatinine, respectively (corresponding mercury plasma levels were 35, 9.4, 5.3, and 2.8 nmol/L, respectively) (Molin et al. 1991).

Blood and hair monitoring are most commonly used as indicators of body burden following exposure to methylmercury compounds. Mercury levels in these media have been found to be influenced by fish consumption patterns. For individuals consuming little fish, about 95% of blood mercury levels are less than 0.3 mg/100 mL and hair concentrations are less than 2  $\mu\text{g}$  mercury/g. However, blood mercury levels may exceed 5 mg/100 mL in individuals with high dietary intakes of fish. Total mercury in human blood and hair in individuals with no known exposure to mercury was reported to be 0.1–5.0  $\mu\text{g}/100$  mL and 1.0–5.0  $\mu\text{g}/\text{g}$ , respectively (Goldwater and Stopford 1977). The mercury content in human hair was studied in Japanese couples, with husbands having significantly higher mercury concentrations (4.01  $\mu\text{g}/\text{g}$ ) than wives (1.99  $\mu\text{g}/\text{g}$ ), possibly as a result of greater fish consumption among the men (Chen et al. 1990).

Blood and urine monitoring may be useful for groups of workers subject to chronic exposure to mercury, but the relative contribution of recent exposures to mercury levels in these media, in comparison to releases of mercury stored in tissues as a result of earlier exposures, is not well understood (EPA 1984b).

## 5.6 POPULATIONS WITH POTENTIALLY HIGH EXPOSURES

Mercury exposure of the general public occurs via several mechanisms. For example, numerous studies have reported increased levels of mercury in water, air, and foliage surrounding industries that use mercury (Lodenius and Tulisalo 1984; Shaw et al. 1986; Yamaguchi et al. 1971). Significant concentrations of mercury were detected in sewer overflows and urban runoff as well (Murphy and Carleo 1977). Thus, general population exposure to mercury may be higher in industrial and urban areas.

Increased exposure to mercury has also been reported in children of workers who are occupationally exposed to the compound (Hudson et al. 1987). The population of children that is at the highest risk consists of those whose parents work in facilities that use mercury but where no protective uniforms or footwear are used. The mercury is thought to be transferred to the workers' homes in their clothing and shoes.

People with dental amalgams that contain mercury may have greater exposure. Increased breath levels of mercury ranging from 0.1 to 6.2 ng/L (mean 8.2 ng/L) were detected in 167 persons with dental restorations as compared to 0.008–0.1 ng/L (mean 0.06 ng/L) in 5 persons with no amalgams (Patterson et al. 1985). Dentists and other dental professionals also may have greater exposure to mercury as a result of preparing and applying the dental amalgams (Ayyadurai and Krishnashamy 1988; Skare et al. 1990).



Mercury exposure is also increased in persons who eat contaminated fish (Buzina et al. 1989; Cappon and Smith 1982; Phelps et al. 1980). Mercury concentrations in the blood of mothers and infants in Greenland were closely correlated with the amount of marine animal meat the mothers consumed. Mercury concentrations for mothers eating primarily imported food ranged from 11.0 to 32.7  $\mu\text{g/L}$  (concentrations in the blood of their children ranged from 15.0 to 51.4  $\mu\text{g/L}$ ), whereas mothers who consumed a local diet heavy in marine animals ranged from 16.4 to 44.6  $\mu\text{g/L}$  (27.5–140.0  $\mu\text{g/L}$  for their children) (Hansen 1991). Cooking of mercury-contaminated fish does not reduce its mercury content (Armbuster et al. 1988).

Persons using skin lightening creams and soaps containing mercury are also exposed to higher levels than the general population (Barr et al. 1973; Lauwerys et al. 1987). Prenatal and early postnatal exposure of infants to mercury from maternal use of these products is a source of particular concern (Lauwerys et al. 1987). The use of other products that contain mercury such as laxatives and antimicrobial agents can lead to increased exposure as well. Two cases have been reported of chronic mercury exposure from laxative abuse (Davis et al. 1974; Wands et al. 1974).

Increased exposure to mercury has been reported from accidental causes, such as broken thermometers (Agner and Jans 1978) and the misuse of mercury as a cleaning agent (Jaffe et al. 1983). The use of fluorescent tube compactors by industrial facilities may also expose workers in adjacent areas or those working the compactors to increased levels of mercury if proper filters, scrubbing devices, and ventilation are not used (Kirschner et al. 1988).

Populations living near hazardous waste sites may be at risk for exposure to high levels of mercury as a result of mercury contamination of surface waters or soils. However, the available data are insufficient to allow for the characterization of the sizes of these populations or intake levels of mercury to which they are exposed.

## 5.7 ADEQUACY OF THE DATABASE

Section 104(i)(5) of CERCLA, as amended, directs the Administrator of ATSDR (in consultation with the Administrator of EPA and agencies and programs of the Public Health Service) to assess whether adequate information on the health effects of mercury is available. Where adequate information is not available, ATSDR, in conjunction with the NTP, is required to assure the initiation of a program of research designed to determine the health effects (and techniques for developing methods to determine such health effects) of mercury.

The following categories of possible data needs have been identified by a joint team of scientists from ATSDR, NTP, and EPA. They are defined as substance-specific informational needs that if met would reduce the uncertainties of human health assessment. This definition should not be interpreted to mean that all data needs discussed in this section must be filled. In the future, the identified data needs will be evaluated and prioritized, and a substance-specific research agenda will be proposed.

### 5.7.1 Identification of Data Needs

**Physical and Chemical Properties.** The physical and chemical properties of metallic mercury and its inorganic compounds have not been well characterized to permit estimation of their environmental fate (Budavari et al. 1989; Osol 1980; Sax 1984; Spencer and Voigt 1968; Verschuere 1983; Weast 1988; Weiss 1986). Values are needed for the  $\log K_{ow}$ ,  $\log K_{oc}$ , Henry's law constant, and vapor pressure. Experimental data exist which characterize the environmental fate of metallic mercury. Further study of the physical and chemical properties of organic compounds of mercury, especially methylmercury, would help in predicting their environmental fate.

**Production, Import/Export, Use, Release, and Disposal.** Mercury is currently being produced. The estimated world mine production of mercury in 1989 was 5,840 metric tons (Reese 1991). U.S. mercury

## 5. POTENTIAL FOR HUMAN EXPOSURE

production by recovery from secondary sources was 137 metric tons in 1989 and 140 metric tons in 1990 (Reese 1991). Domestic production of mercury has been characterized by abundant supply and slowly declining demand for the last 2 decades (DOI 1989). The declining production trend is expected to continue (DOI 1989). Mercury is used in the production of many manufactured products (Carrico 1985; Drake et al. 1981; Grayson 1983; Windholz 1983). The domestic use pattern of mercury in 1990 was as follows: 33% was used in electrical and electronic applications, 33% was consumed in the manufacture of chlorine and caustic soda, and 34% was used for applications such as measuring and control instruments, dental equipment, and paint (Reese 1991). Mercury is released to the air, water, and soil from both natural sources and human activity (Andersson 1979; Baldi 1988; Clayton and Clayton 1981; Dean et al. 1972; EPA 1971c, 1987f; Germani and Zoller 1988; Gavis and Ferguson 1972; Glass et al. 1990; Glasser et al. 1991; Levins et al. 1979; Lindberg 1984; TRI89 1992; WHO 1976). Current disposal methods for mercury are efficient (Carrico 1985; DOI 1989; EPA 1975a, 1975b). Information exists on the amounts of mercury disposed of by each method (Carrico 1985; DOI 1989; EPA 1975a, 1975b). Current regulations exist regarding the control of emissions of mercury (Carrico 1985; EPA 1975a, 1975b). No information of regulations was found regarding recycling of mercury.

According to the Emergency Planning and Community Right-to-Know Act of 1986, 42 U.S.C. Section 11023, industries are required to submit chemical release and off-site transfer information to the EPA. The Toxics Release Inventory (TRI), which contains this information for 1990, became available in May of 1992. This database will be updated yearly and should provide a list of industrial production facilities and emissions. shows that 195,460 pounds of mercury were released or transferred off-site by facilities required to report to the TRI (TRI90 1992).

**Environmental Fate.** Mercury released to the atmosphere may be transported long distances before being removed by wet or dry deposition. Residence time in the atmosphere has been estimated to range from 60-90 days to 0.3-2 years (Andren and Nriagu 1979; EPA 1984b; Glass et al. 1991). Volatile forms of mercury released in water or soil enter the atmosphere, but most mercury sorbs to soil and sediment (EPA 1984b; Meili et al. 1991). Sorbed mercury may be reduced to elemental mercury or bioconverted to volatile organic forms (Andersson 1979; Callahan et al. 1979; EPA 1984b). The major transport and transformation processes involved in the environmental fate of mercury, as it relates to potential human exposure, have been fairly well defined. The sizes and fluxes of the environmental compartments, and the mechanisms and rates of several processes involved in the biogeochemical cycling of mercury are still undefined. However, the most important fate process for human exposure, bioaccumulation in aquatic food chains, is well understood.

**Bioavailability from Environmental Media.** Metallic mercury vapors in the air are readily absorbed following inhalation exposure while inorganic and organic mercury compounds are poorly absorbed (Berlin et al. 1969a). Oral absorption of organic mercury is nearly complete (Aberg et al. 1969) while oral absorption of inorganic mercury is low (Clarkson 1989; Friberg and Norberg 1973). Metallic mercury vapor can be absorbed following dermal exposure (Hursh et al. 1989); however, dermal absorption of the vapor comprises a much smaller percentage than absorption through the inhalation route. Inorganic mercury salts can also be dermally absorbed (Schamberg et al. 1918). Data are needed regarding the bioavailability of organic mercury from contaminated water, soil, or plant material.

**Food Chain Bioaccumulation.** Mercury is known to bioconcentrate in aquatic organisms and biomagnify in aquatic food chains (Callahan et al. 1979; EPA 1980a, 1980e, 1984b). While bioconcentration in the aquatic food chain is well studied, little is known about the bioaccumulation potential for terrestrial food chains, although it appears to be small (Lindqvist 1991b). Information on the potential for terrestrial food chain biomagnification would be useful in light of the binding of mercury to organic matter in soils and sediment.

**Exposure Levels in Environmental Media.** Environmental monitoring data are available for mercury in ambient air, surface water, groundwater, drinking water, sediments, soils, and foodstuffs (EPA 1980a,

1984b, 1985c; Glass et al. 1990; NAS 1977; Lindqvist 1991f); however, additional monitoring data on mercury levels in all environmental media, particularly drinking water, would be helpful in determining current exposure levels. Estimates of human intake from inhalation of ambient air and ingestion of contaminated foods and drinking water are available (EPA 1984b), although some of these estimates are not current and may no longer be representative of present levels.

Reliable monitoring data for the levels of mercury in contaminated media at hazardous waste sites are needed so that the information obtained on levels of mercury in the environment can be used in combination with the known body burden of mercury to assess the potential risk of adverse health effects in populations living in the vicinity of hazardous waste sites.

**Exposure Levels in Humans.** Mercury can be measured in human blood, hair, and urine (EPA 1984b; WHO 1990). The most common method of assessing human exposure in the workplace involves the measurement of mercury in urine (Bell et al. 1973; Roels et al. 1987; Lindstedt et al. 1979; Rosenman et al. 1986). Urine mercury levels have been correlated with ambient air exposure levels, particularly mercury vapor. Dietary intake levels, particularly resulting from the consumption of contaminated fish, have been determined by blood and hair monitoring (EPA 1984b). Additional information on the biological monitoring of populations living in the vicinity of hazardous waste sites would be helpful in estimating exposure of these populations to mercury compounds.

This information is useful for assessing the need to conduct health studies on these populations.

**Exposure Registries.** New York State has instituted a Heavy Metals Registry that monitors occupational exposure to heavy metals including mercury. Cases are reported when mercury exposure is equal to or exceeds 5  $\mu\text{g/L}$  in blood or 20  $\mu\text{g/L}$  in urine. Between 1982 and 1986, 1,000 cases of mercury exposure were reported and linked to 47 companies. Most exposure (494 cases) occurred in workers in the alkali and chlorine industry where mercury is used as a cathode and exposure occurs when the cells are opened; the median blood mercury concentration was 76  $\mu\text{g/L}$  (maximum concentration 916  $\mu\text{g/L}$ ). The second most frequent exposure category (213 cases) was the manufacture of industrial instruments during the manual assembly and fabrication of thermometers; median blood mercury concentration was 145  $\mu\text{g/L}$  (maximum 889  $\mu\text{g/L}$ ) (Baser and Marion 1990).

This substance is not currently one of the compounds for which a subregistry has been established in the National Exposure Registry. The substance will be considered in the future when chemical selection is made for subregistries to be established. The information that is amassed in the National Exposure Registry facilitates the epidemiological research needed to assess adverse health outcomes that may be related to exposure to this substance.

### 5.7.2 On-going Studies

Long-term research studies on the environmental fate of mercury have not been identified. However, remedial investigations and feasibility studies at the 617 NPL sites known to be contaminated with mercury should add to the current knowledge regarding the transport and transformation of the compound in the environment.

Environmental monitoring being conducted in conjunction with remedial investigation/feasibility studies at the 617 NPL sites contaminated with mercury (EPA 1988h) should also add to the current database on environmental concentrations of the compound.

No on-going studies or long-term research concerning occupational or general population exposures to mercury were identified.